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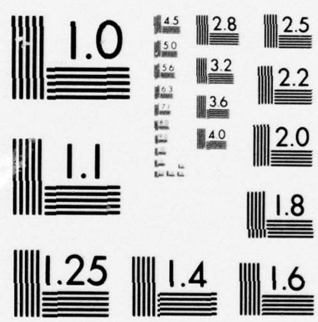

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- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
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PREFACE

In the late 1960's and early 1970's the Structures and Materials Panel of AGARD supported a programme of activities in the field of acoustic fatigue under the direction of a Working Group chaired by Mr A.H.Hall. A notable achievement of that programme included a survey undertaken by Professor B.L.Clarkson, the Panel's Co-ordinator on acoustic fatigue. This led to the preparation of an inventory of acoustic fatigue test facilities available within NATO, as at 1969, and a major symposium on acoustic fatigue held in September 1972. Finally, between 1970 and 1974, six of the NATO countries collaborated in the acquisition of design data and agreed on procedures for their analysis and interpretation by the Engineering Sciences Data Unit for the preparation of design data sheets. These data sheets were published by AGARD as the four parts of AGARDograph 162.

The Panel decided that, some two years after the data sheets had been introduced, a review should be made of acoustic fatigue activities in the NATO countries as a guide to the need for any additional action in this subject and also to assess the use which had been made of the data sheets which the Panel had published. This present publication includes the five national papers presented at the Review Meeting together with a summary of the discussions and conclusions reached.

In ~~his~~ THE opening remarks, the Chairman of the Review Meeting, Professor B.L.Clarkson, observed that one of the objectives of the Panel's activities, including the publication of the data sheets, had been to present the practising designer with simplified tools to enable him to overcome what had previously been complex design problems. It has been said that problems with acoustic fatigue have now been largely overcome; the extent to which this is true and the extent to which variants of the old problems have arisen may be assessed from the papers which follow.

The Structures and Materials Panel is most grateful to the authors of these papers and all who took part in the discussions which followed their presentation.

Anthony J.BARRETT

CONTENTS

REVIEW OF ACOUSTIC FATIGUE ACTIVITIES IN GERMANY

by

Gerhard Bayerdörfer

IABG/Ottobrunn
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SUMMARY

During recent years the German aircraft industry has been engaged in projects like the European Airbus A 300 B, the shorthaul transport VFW 614 and, on the military side, the vertical take-off VAK 191, the MRCA, and the Alpha-Jet. In line with the international division of manufacture the German firms looked mainly on the structural problems of the parts they made themselves. The acoustic fatigue investigations described in this paper therefore cover only the problems inherent to the German-manufactured parts of the aircraft. Besides this project-oriented work studies of a more fundamental nature were concerned with technology.

For the European space industry, a number of qualification tests were carried out on spacecraft such as Helios, Cos B, Meteosat OTS, ISEE-B and MAROTS.

1. WORK ON AERONAUTICAL PROJECTS

VFW 614 (VFW-Fokker)

The particular configuration of this aircraft with the engines mounted on the wing is shown in Fig. 1. The shaded parts were considered to be sensitive to acoustic fatigue, so special provisions were taken. Acoustic fatigue estimations were made for the following structural parts

- tailplane and elevator
- fin and rudder
- rear fuselage.

The estimation of stresses and the corresponding fatigue life was based on the AGARD Data Sheets. It was shown that the nominal fatigue life of 60.000 flights was safely covered by the calculations. In addition to the fatigue life calculations, strain-survey tests made on two representative parts of the elevator and rudder structure showed good agreement with the calculations. A final check using noise and strain measurements was taken during a ground run of the G 2 prototype. At no location, the measured stresses were higher than the predicted ones. The results are documented in (1).

As part of a new technology program sponsored by the German Ministry of Defense, VFW-Fokker developed smaller components of the VFW 614, such as spoiler and undercarriage doors in boron-, carbon and glass fibres. In addition to passing other tests, these specimens were used to determine their damping properties. The investigations carried out on three doors and two spoilers were performed by tuning loadspeakers to the dominant panel modes (Fig. 2). The excitation was then switched off, and the decaying response of the testspecimen recorded, so that the damping values could be determined. Each test specimen was excited at six dominant modes in the 200 - 2.000 Hz frequency range. The averaged damping factor δ of the five specimens tests is shown in Fig. 3. By comparing components of identical shape, including hinges, it became clear that the boron fibre specimen provided an enormous increase in damping compared with riveted skin / rib design (2). On the other hand it was found that glass fibre structures provide less damping than conventional design.

VAK 191 B (VFW-Fokker, Fiat)

For this aircraft, an extensive measuring program was carried out in 1975 when VFW-Fokker had a cooperation contract with the US Navy. Sound and strain measurements were taken for various flight and take-off conditions such as conventional take-off, short take-off and vertical take-off. Fig. 4 shows the estimated sound contours for the STOL case.

MRCA (MBB, BAC, AIT)

The breakdown of final assembly for this aircraft is shown in Fig. 5. As far as the German part manufactured by MBB is concerned, acoustic fatigue problems are expected only in the inner part of the intake duct. Under certain flight conditions very high noise levels have been measured there and considerable care has been given to this problem. The difficulties are increased by the occurrence of hammer shocks which cannot be simulated with current test equipment, nor is it possible to calculate their structural response on the basic of simple theories. It is felt that a gap exists in suitable tools to treat this phenomen on and future research should concentrate on this problem.

According to MBB, the AGARD Data Sheets are of great value not only because of the relatively precise

predictions they permit but also as a common calculation method to be used in national and international cooperation programs.

A 300 B (Aêrospationale, MBB, VFW-Fokker, HSA)

Because of the quiet engines of this aircraft, no acoustic fatigue problems were expected for the rear fuselage and empennage. The actual flight service of the first production aircraft, however, showed that, depending on the flight missions, failures in the rudder occurred after about 300 flying hours. These failures were concentrated in the lower part of the rudder (Fig. 6) close to the gap between the fuselage and rudder. Flight measurements showed that the structural response in terms of g_{rms} increased with speed, with the lowest skin panels of the rudder developing the highest values. So it was concluded that the excitation has to be seen in high aerodynamic turbulence generated by the gap.

In order to simulate these aerodynamic effects, an acoustic fatigue test was performed inside a reverberation chamber of 206 m^3 (Fig. 7). The first test specimen, which was of the same structural configuration as the rudders in service, was used to calibrate the facility. The calibration was performed by controlling the noise generation system in such a way as to obtain the same structural response as measured during flight. It turned out that a broad-band spectrum peaking at about 100 Hz with an OASPL of 141 db produced the same acceleration spectra.

After stress survey tests at different sound-pressure levels, which showed a strong nonlinear relationship between excitation and response (Fig. 8), the test specimen was fatigued at a sound-pressure level of 155 db. The failure modes which occurred were of the same nature as the ones encountered in service. This led to the conclusion that acoustic excitation is a good method to simulate aerodynamic turbulence so that further tests with improved designs could follow. The results of the fatigue tests were used to estimate the fatigue life under normal service loadings. Because of the high test-acceleration, the fatigue-life estimates are covered with uncertainties which cannot be quantified. So the results were mainly used for comparison (3).
The field of accelerated testing certainly needs further research, which would be a worthwhile task for the AGARD Working Group

Structural Absorbers

This development program which is not related to a specific project, is designed to produce sound-absorbing structures which, in addition to good acoustical efficiency, have structural properties enabling them to carry loads. A possible application may be that in a pure fan nacelle as shown in Fig. 9. The program is especially concerned with the optimization of absorption over a broad frequency range. For this purpose new combinations of sandwich-type build-up are being investigated. Every design is also tested for static and fatigue strength. As the program is still underway, no final results can be presented.

2. WORK ON SPACE PROJECTS

For the European space industry, a number of qualification tests have been carried out by IABG. Spacecraft such as Helios, Cos B, Meteosat, OTS, ISEE-B and MAROTs were subjected to acoustic noise tests in their fully integrated configuration. These tests are taken under reverberant conditions to simulate the critical launch phase. The acoustic spectrum is normally defined in octave band levels in the 31,5 Hz to 10 kHz frequency range. The time of exposure during lift-off and test is about 2 min. Fig. 10 shows the structural model of Meteosat in a reverberation chamber.

A major part of the present space activities are directed towards the development of the European Spacelab, whose dimensions are one order of magnitude larger than those of the automatic satellites.In order to check whether such big test specimens can be tested in excisting facilities, a pretest was performed with a wooden mock-up of the spacelab module (Fig. 11).

The criteria for acceptance of the facility were the acoustic spectrum achievable and the scatter of the sound-pressure levels of the individual microphone positions. Fig. 12 shows the results for the empty chamber. The averaged sound-pressure level of 8 microphones distributed around the test specimen falls within the tolerance band, except for very low frequencies. As the cut-off frequency of the largest horn is 37 Hz, sufficient acoustic power can only be expected for frequencies higher than 40 Hz.

After installing the mock-up in the chamber, the tests were carried out with the same power setting in two test positions. The results of position I are presented in Fig. 13. As can be seen, a reduction of sound-pressure levels occurred in the 160 Hz to 1 kHz frequency band. This is doubtless the absorbant effect of the wooden mock-up. By increasing the acoustic power output of the noise generators, the levels can be increased so as to fulfill the requirements of the test specification.

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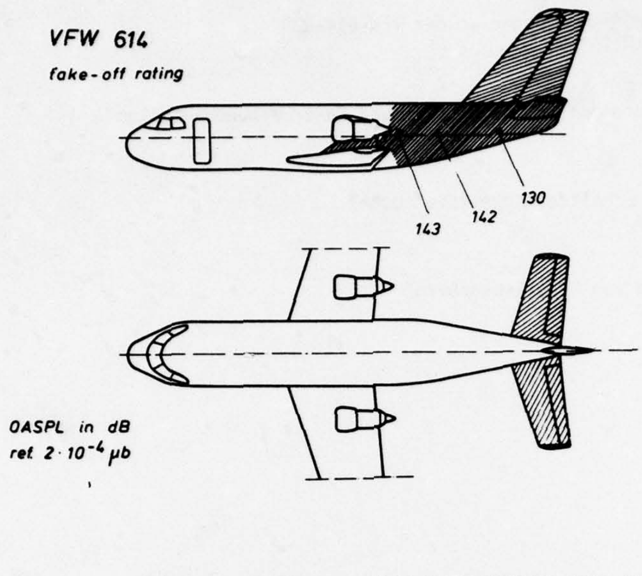

FIG. 1 VFW 614, FATIGUE LIFE PREDICTION FOR AREAS OF ELEVATED NOISE LEVELS

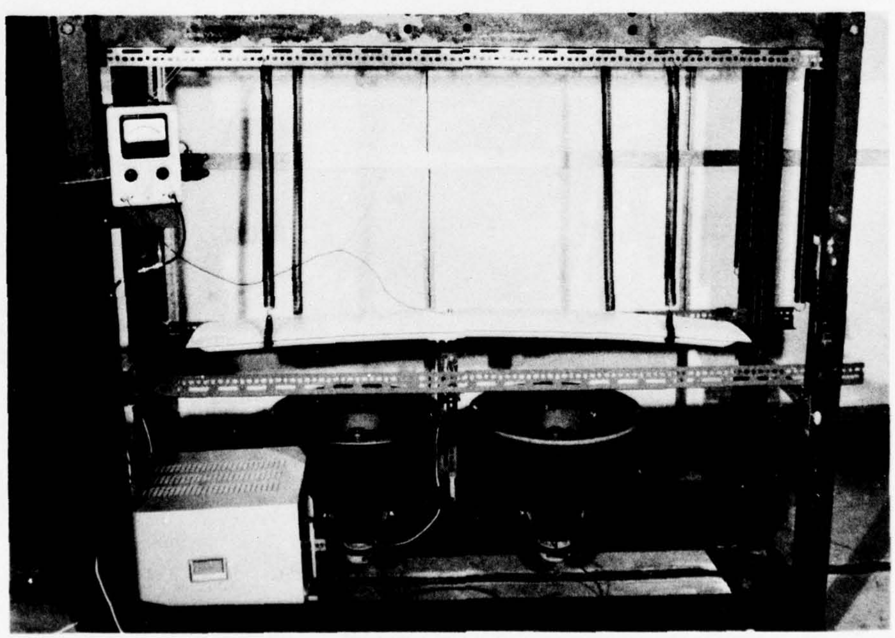

FIG. 2 DAMPING INVESTIGATION ON VFW 614 UNDER-CARRIAGE DOOR

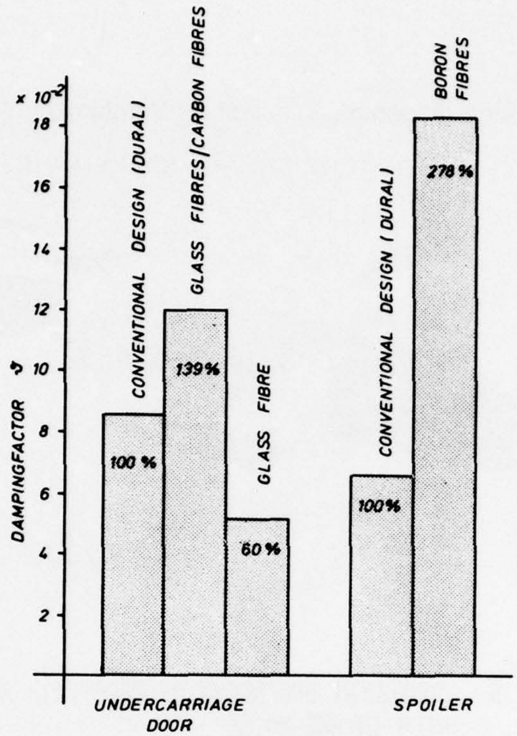

FIG. 3 COMPARISON OF DAMPING FACTORS

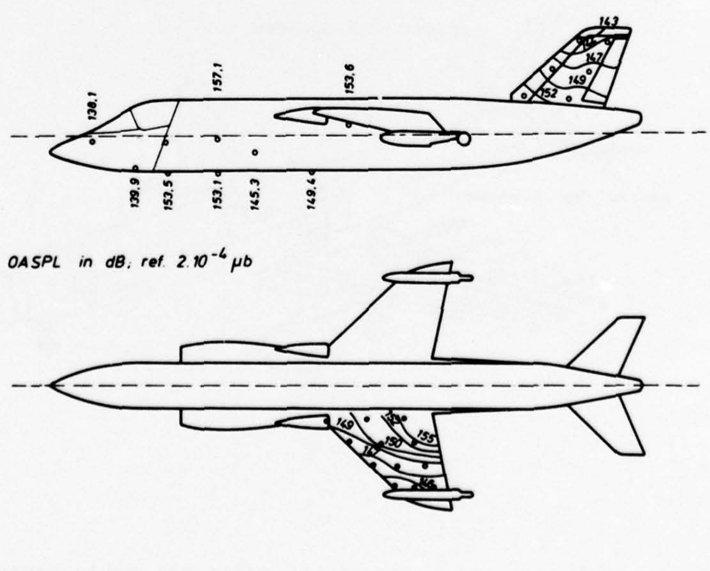

FIG. 4 NOISE PREDICTION FOR VFW/FIAT VAK 191 B
(SHORT TAKE-OFF)

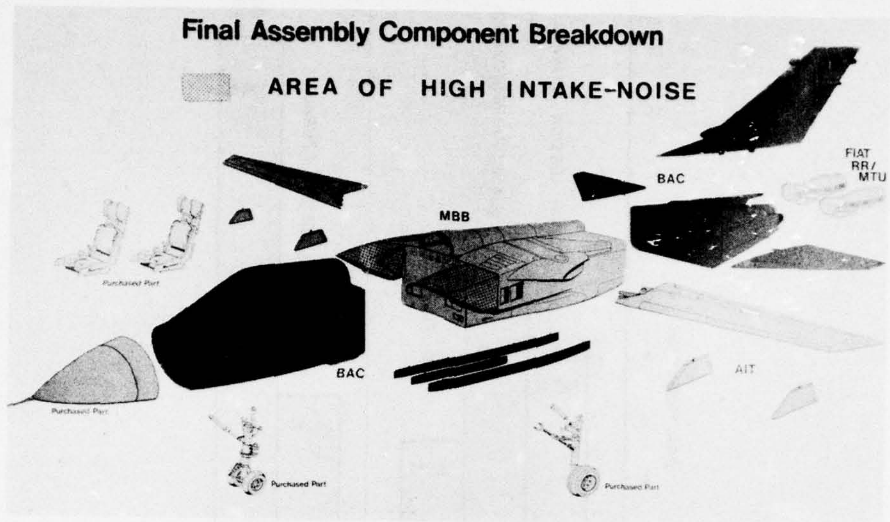

FIG. 5 COMPONENT BREAKDOWN OF MRCA WITH AREAS OF HIGH INTAKE-NOISE

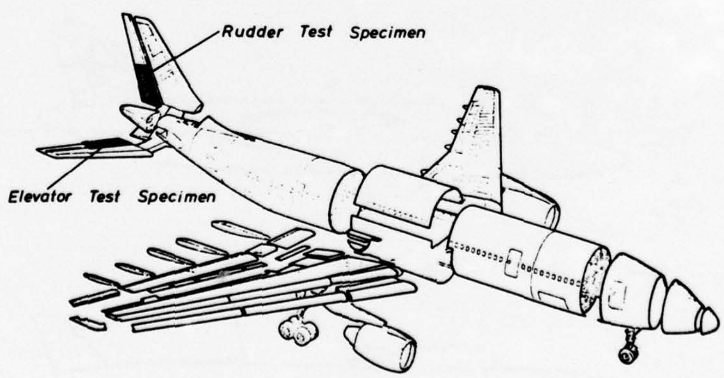

FIG. 6 AIRBUS A 300 B STRUCTURAL PARTS FOR SONIC FATIGUE TEST

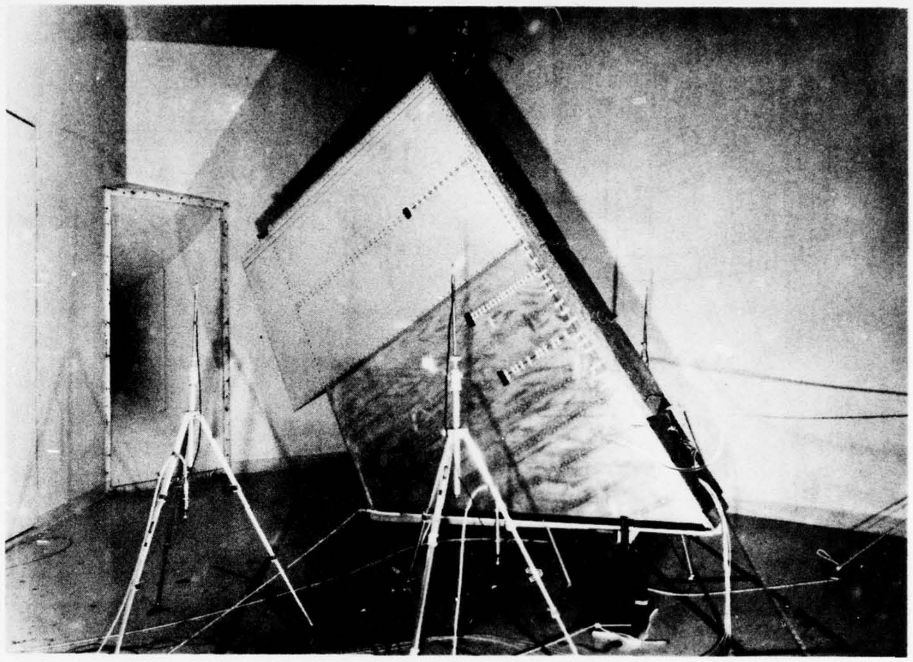

FIG. 7 LOWER PART OF A 300 B RUDDER IN REVERBERATION CHAMBER

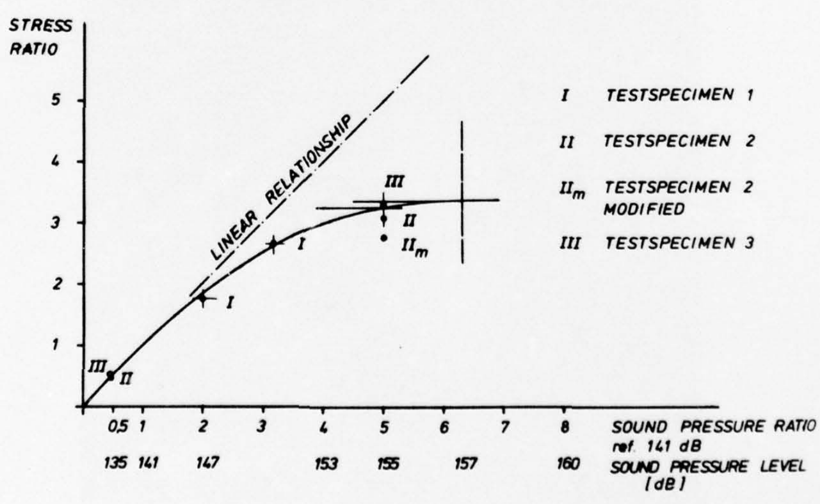

FIG. 8 A 300 B - RUDDER, NONLINEARITY OF STRUCTURAL RESPONSE

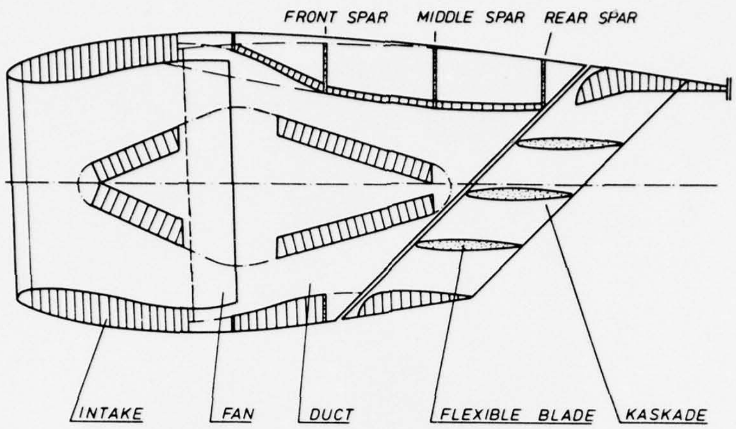

FIG. 9 SCHEMATIC LAY-OUT OF A PURE-FAN NACELLE WITH STRUCTURAL ABSORBERS

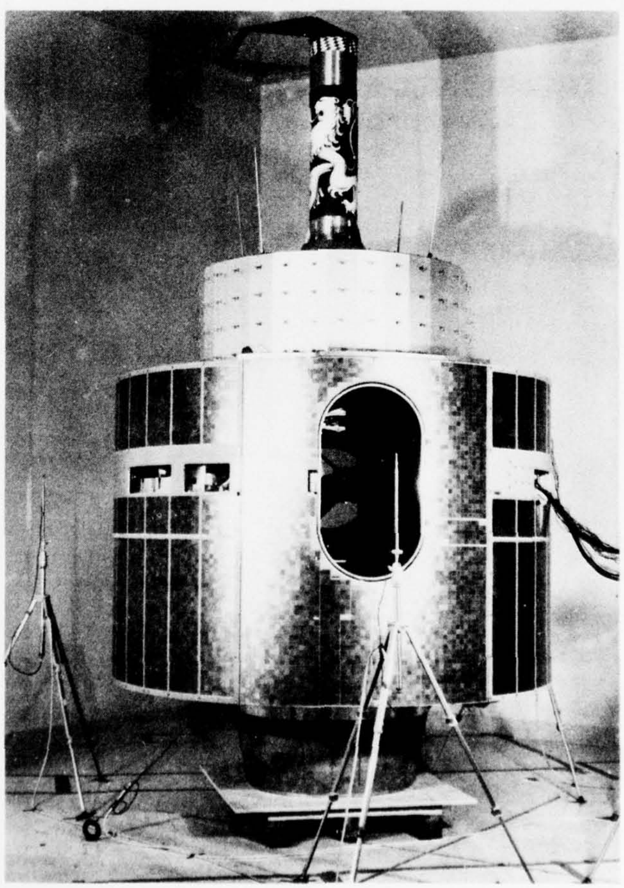

FIG. 10 METEOSAT-SPACECRAFT IN REVERBERATION CHAMBER

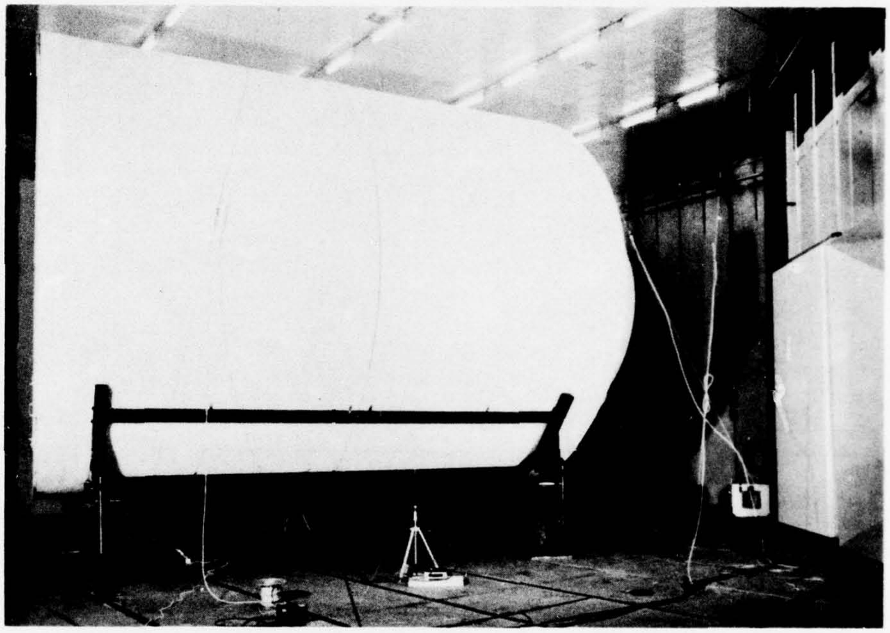

FIG. 11 WOODEN MOCK-UP OF SPACELAB- MODULE IN TEST CHAMBER

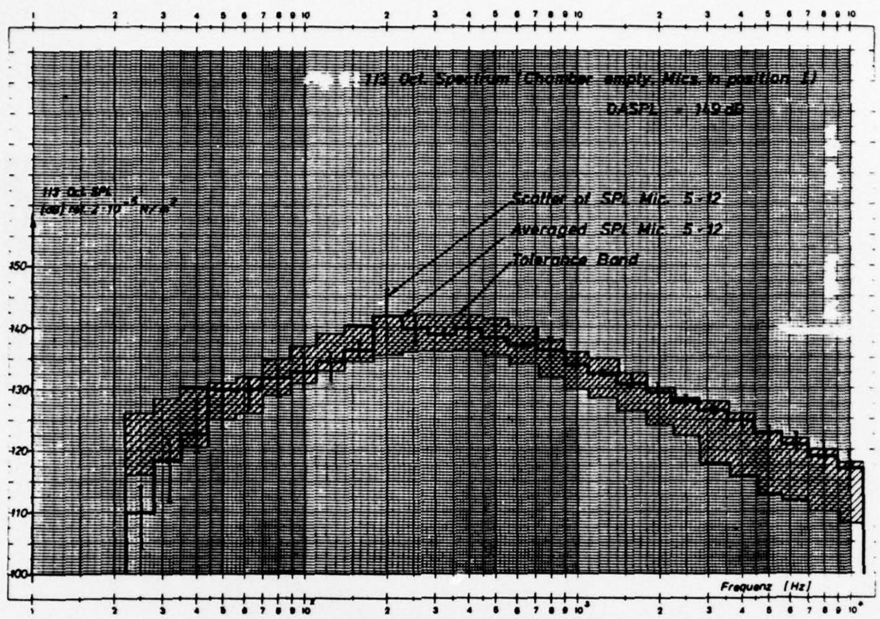

FIG. 12   1/3 OCT. TEST SPECTRUM FOR EMPTY TEST CHAMBER

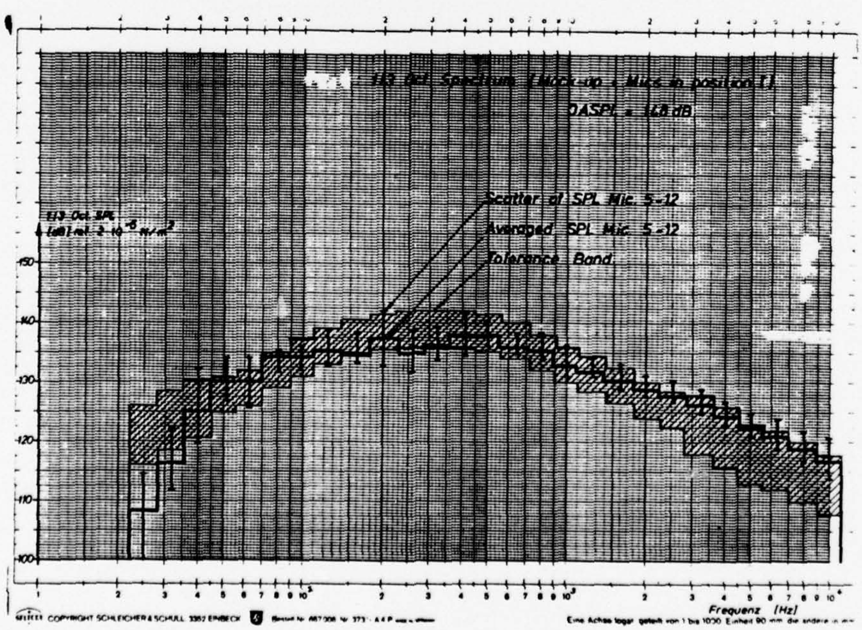

FIG. 13   1/3 OCT. TEST SPECTRUM FOR TEST CHAMBER OCCUPIED BY SL MOCK-UP

REVIEW OF ACOUSTIC FATIGUE ACTIVITIES IN ITALY

by

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AERITALIA, Torino

SUMMARY

After a short description of the last works carried out by AERITALIA and FIAT in the field of applied research on Acoustic Fatigue, reported in past AGARD Specialist Meetings, two main research programs sponsored by Consiglio Nazionale delle Ricerche, at present under development, are illustrated.

For both programs theoretical and experimental research works are to be cooperatively carried out in two years among the "Istituto di Progetto di Aeromobili" Politecnico di Torino, the "Istituto de Ingegneria Aerospaziale" Politecnico di Milano, the "Istituto di Aeronautica" Università di Pisa and the AERITALIA, the latter only for the second subject shown below.

The actual subjects are:

– Fatigue Phenomenons and Behaviour of Aeronautical Structures under Acoustic Loads.
– Research on Fracture Mechanics of Pressurized Space Structures subjected to Acoustic Fatigue.

Lastly, some indications for new work in Acoustic Fatigue are given.

INTRODUCTION

In the recent years, as it has been reported in previous Meetings of the Structures and Materials Panel (see References) a systematic research has been carried out in Italy in the field of acoustic fatigue as applied to aircraft structures. This activity was performed in the late sixties under the development programme for the VAK 191B airplane which, as known, has been jointly realized by VFW-FOKKER and FIAT-AERITALIA.

The considerable amount of activity carried out at that time permitted to acquire analysis methods, experimental techniques and test means as a basis for further researches.

In particular, methods for evaluating the acoustic pressure on surfaces were established using scale models[1]; in addition temperature and acoustic level surveys were conducted on a scale 1/4 similarity model to locate the critical areas for the different foreseen takeoff configurations[2].

Subsequently fatigue tests were carried out on airplane structural components, in the critical areas as derived from previous investigations, reproducing, when requested, the thermal conditions of the aircraft structure[3].

It is interesting to underline the fact that the results of the nearfield noise measurements on model were compared to empirical calculations according to a method based essentially on the Data Sheet of the Engineering Sciences Data Unit: the agreement proved to be quite satisfactory, mainly in the conventional take-off condition, whilst in the short and vertical take-off conditions some difference appeared, due to the presence of jet blowing on the ground[1].

The experimental facilities available at the Centro Ricerche Fiat – Torino, besides to the instruments familiar for this type of research (such as condenser imcrophones for high sound level, level indicators, octave band, 1/3 octave band and continuous spectrum analyzer, and a 14 track magnetic tape recorder consist of:

An air-blowing facility (Mass Flow = 12 kg/sec) feeding the test bench for acoustic simulation on aircraft model with cold and/or hot jets;

An acoustic fatigue test facility, composed of a progressive wave tube for testing on panels and a reverberant room (32 m^2) to test structural components.

PRESENT ACTIVITY

Two main theoretical and experimental research programs sponsored by Consiglio Nazionale delle Ricerche are at present under development in Italy. They are:

(a) Fatigue Phenomena and Behaviour of Aircraft Structures under Acoustic Loads

This program is cooperatively carried out among the "Istituto di Progetto Aeromobili" Politecnico di Torino, the

"Istituto di Ingegneria Aerospaziale" Politecnico di Milano and the "Istituto di Aeronautica" Università di Pisa.

The program is articulated as follows:

1st Stage: Survey on bibliography on this field and collation of analytical methods.

2nd Stage: Theoretical research, agreed between the three Institutes, to ascertain the theoretical forecasts on the dynamic behaviour of specimens as well as structural members, using data on some physical properties of materials (internal damping) obtained from "ad hoc" tests and comparing with the relevant Data Sheet of the Engineering Sciences Data Unit.

3rd Stage: Investigation on the fatigue behaviour of specimens reproducing typical shapes of panels subjected to prevailing constant loads and alternating loads of a relatively small amplitude.

4th Stage: Investigation on the acoustic fatigue behaviour of structural members incorporating typical panel shapes among those selected in the previous stage.

5th Stage: Analysis of the relationship between behaviour of specimens and behaviour of structural members incorporating said specimens, in view of a formulation of criteria using test results on specimens to forecast the structure behaviour.
Comparison between fatigue life per Data Sheet of ESDU and fatigue life found by testing.

Test Specimens

For the fatigue tests, structural specimens called "simple elements" are used with riveted or integral stiffeners, using three different dimensional parameters and six samples per type. For the acoustic fatigue tests, panels are utilized with riveted stiffeners of three types (width 480, 488 and 495 mm, length 76 mm) using three samples per type.

Test Equipment

For the fatigue tests, a pulsating load machine with imposed deformation and a pulsating bending machine with tension preloading are utilized; both machines are designed and manufactured by the "Istituto di Progetto Aeromobili" of Politecnico di Torino. For the resonance, damping and acoustic fatigue tests, on the structural panels the progressive wave tube of the "Centro Ricerche Fiat – Torino" is used. At the present the research is already completed 20% for the experimental work and 40% for the theoretical work.

(b) Research on Fracture Mechanics of Pressurized Space Structures Subjected to Acoustic Fatigue

This program is cooperatively carried out among the "Istituto di Progetto Aeromobili" Politecnico di Torino, the "Istituto di Ingegneria Aerospaziale" Politecnico di Milano, the "Istituto di Aeronautica "Università di Pisa and the Aeritalia – Space Sector.

As known the aerospace structures of advanced type present complex design problems mainly due to possible catastrophic failures originated by undetected flaws. These are defects already existing in the material and/or introduced during manufacture and not detectable by N.D.I. means. They are liable to grow due to the stresses caused by pressurization and the dynamic stresses induced by the noise generated by the propulsion system. The dimension of the crack originating from said defect may become critical and such as to determine a fracture and an explosive decompression (Break Before Leakage, BBL) with catastrophic implications. The aim in case of growing cracks is to assure a gradual unexplosive decompression by gas leakage without fractures (Leakage Before Break, LBB). To this purpose the following points are required:

(a) A reliable statistics for all possible structure defects.
(b) An evaluation of the growth mode and time for these defects.
(c) An evaluation of the critical dimensions of the crack grown from the defect.
(d) A research of materials and manufacture solutions suitable for assuring a LBB behaviour.

Development of the program now defined, in actions and times, is articulated as follows:

1st Stage (2 years): Refinement of methods useable at design level and experimental substantiation.

2nd Stage (2 years): Deep study and widening of subjects developed in the first stage with reference to more complex structures.

The research has recently begun.

SUGGESTIONS FOR NEW WORK

In our opinion two subjects could be developed.

The first subject deals with the analysis and experimentation of the acoustic field of one jet, or more, with ground effect. As said in the Introduction[1] the comparison between experimental data and analysis according to a method based essentially on the Data Sheet of the ESDU was quite satisfactory in the case of jets tangent to the ground, whereas it showed some differences for jets blowing on the ground. The probable cause is the complex interaction of the waves reflected by the ground. A theoretical-experimental research in this field would complete the considerable amount of data, very useful to the designer, so far gathered in the ESDU Data Sheets.

The second subject deals with the aerodynamically originated noise from boundary layer. it would be interesting to have Design Data available, in form of Data Sheets, defining the noise field in terms of geometrical and aerodynamic parameters around wing and fuselage structures. This will assist the designer both for acoustic fatigue and internal noise calculations.

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REVIEW OF ACOUSTIC FATIGUE ACTIVITIES IN THE USA

by

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SUMMARY

In this paper recent and current sonic fatigue research and development programs are reviewed. The areas discussed include load criteria, development of long life sonic fatigue design criteria for weldbonded and bonded structures, composites and honeycomb panels for high temperature application. Recent advances and planned programs in testing techniques are also presented. These include the determination of structural mode shapes by computer techniques and development of a programmable high cycle fatigue testing system designed to obtain coupon specimen data to 10^9 cycles or above. Finally, proposed work is presented. Publications concerning the program discussed are listed for further reference.

INTRODUCTION

Fatigue failures in aircraft structure induced by high intensity noise continue to be of concern to the designer. The numerous failures which occurred on jet aircraft in the late 1950 and early 1960 time periods have been largely eliminated by the development of techniques which deal with the problem on a broad basis. The data and criteria developed are applicable to many types of aircraft structure using mostly aluminum material and riveted joints.

The application of these design methods have been very successful and has reduced maintenance and retrofits to a tolerable level within the service design life of aircraft. When it became necessary to utilize jet aircraft significantly beyond their design life sonic fatigue failures have reoccurred as some recent cases have shown.

The development of new high performance aircraft with extended service life requires a continuing development of sonic fatigue data and principles especially for new materials and types of structures for which marginal data and criteria exist. A case in point is the Short Take-off and Landing (STOL) aircraft, where large areas of the structure are exposed to high noise and temperature levels as well as static stresses caused by air loads. Sonic fatigue failures on STOL aircraft components, such as flaps, could cause a critical safety problem. The rapid accumulation of load cycles on STOL aircraft components and the long exposure times to engine noise requires reliable fatigue design data in the region of 10^9 cycles and above. Similar problems exist on inlet ducts, engine nacelle structure, pylon fairings and engine cowlings which are continuously exposed to severe pressure fluctuations during flight. Systematic sonic fatigue design data for most of these structures do not exist and the designer is forced to work with extrapolations which restrict optimization from a weight viewpoint.

The presently available sonic fatigue analysis and design information is contained in References 1 and 2 and has found general acceptance and application in industry. Analysis and design criteria for advanced structures utilizing composite materials, bonded and weldbonded joints, honeycomb structures for application in regions of high temperatures and high cycle random fatigue data for diverse materials and joints, are not available and need to be developed. Advanced testing techniques are needed to obtain experimental data on a more timely and economical basis.

This survey paper summarizes representative recent and current programs in sonic fatigue related research and development conducted by US industry and the US Air Force Flight Dynamics Laboratory (AFFDL). Table I represents a summary of the survey of sonic fatigue related efforts. The selection of the categories was based on the most representative contributions submitted.

The author wishes to acknowledge the contributions from the staff of the AFFDL Sonic Fatigue Facility, L.Jacobs, Boeing Commercial Airplane Company, Dr M.Jacobson, Northrop Corporation, Ian Holehouse, Rohr Industries, H.Bartel, Lockheed, Georgia, and R.Hancock, Vought Corporation which are incorporated in this paper. Mr N.Wolf from the AFFDL assisted in assembling and editing the material presented.

LOAD CRITERIA

The aeroacoustic loadings associated with flight vehicles result from the propulsion system and from flow phenomena associated with flight through the atmosphere. Numerous techniques have been developed to predict the significant characteristics (intensity, frequency spectrum, temporal and spatial correlation) of the near field environment for both propulsive and aerodynamic noise sources. Many programs from industry, research institutes, government

agencies and sources abroad have contributed significantly to the state-of-the-art of flight vehicle near field noise prediction. Consequently, a multitude of techniques involving equations, and short and complex computer programs have been developed.

The AFFDL is currently sponsoring a program with Bolt Beranek and Newman to compile a technical summary of available near field noise prediction methods for all propulsive and pseudo-noise sources associated with flight vehicles. The result of this effort[3,4] will be published in late 1976. These results review available near field noise prediction methods and provide a guide for their usage by aircraft designers. The guide will include near field noise prediction methods for: turbojet and turbofan engine exhaust; inlet and casing; propeller and rotors; attached transitional and separated boundary layers; base pressure fluctuations; oscillating shocks; cavity pressure oscillation and gunfire blast.

The current interest in STOL aircraft has led to numerous investigations and development concepts. The two primary concepts which have been selected by the US Air Force both employ externally blown flaps. One of these concepts (YC-14) employs the over the wing (OTW) and the other (YC-15) uses the under the wing (UTW) blown flap arrangement. Both of these configurations have substantially increased structural areas exposed to intense aeroacoustic loads. The aeroacoustic loads result from exhaust gases impinging on the structure.

A number of programs are being pursued by the US Air Force, NASA and industry addressing various aspects of the STOL noise problem. The AFFDL is currently supporting a program with the McDonnell-Douglas Aircraft Company to develop methods to predict the aeroacoustic environment for both OTW and UTW blown flap configurations. The program includes an extensive series of model tests designed to provide the influence of design parameters such as thrust, bypass ratio, exit velocity and temperature, flap geometry, etc. on the fluctuating pressures.

Flap loads are being measured on both the YC-15 and YC-14 aircraft through the sponsorship of NASA during the joint USAF/NASA flight tests of these aircraft. These tests include measurements for a number of ground and flight conditions. In addition, the AFFDL and NASA Langley Research Center are jointly sponsoring a program to obtain fuselage acoustic, vibration and internal acoustic measurements on the YC-14 and YC-15 aircraft. These measurements will be made for the same ground and flight conditions as the flap loads tests described above.

The results from the model test data and the full scale aircraft data are expected to provide an excellent data base for defining the aeroacoustic loads associated with OTW and UTW blown flap aircraft.

At Lockheed[5], the noise characteristics of both OTW and UTW blown flap configurations have been extensively investigated under NASA contracts; however, emphasis has been on far-field noise prediction and reduction. These programs have led to an improved definition of basic engine exhaust-wing/flap noise sources relating to the primary jet, wall jet, and trailing edge wake. However, further applied research will be required to define the relationships between these noise sources and oscillatory surface pressures. For instance, flow attachment in the OTW configuration generally requires that the engine exhaust jet be canted or deflected against the wing/flap. This can create complex spatial pressure distributions with local effects such as discrete frequency noise from flow separation bubbles or edges.

Parallel experimental and analytical methods must be developed to complete the prediction of flap and total aircraft vibration loads through the interaction of the aeroacoustic forces and the airframe response. An exploratory program using a 1/8 scale UTW nozzle and plastic model of a slotted flap system was performed at Lockheed. Flap vibration levels and surface pressure data were measured to define the relationship between the response levels of the fundamental bending mode of the flap and local flow velocity. The derived relationship was applied to the NASA/Lockheed Quiet Experimental Short Take-Off and Landing (QUESTOL) design effort to predict flap vibratory loads. These predictions verified that special design considerations must be employed for STOL aircraft to limit flap response and avoid excessive wear and fatigue damage, as well as maintain an acceptable level of ride quality for passengers and crew.

MATERIAL, STRUCTURE AND JOINT DATA

A program was recently completed at the AFFDL that developed an advanced design chart for bonded beaded panels subjected to high intensity noise. Previously published design information for bonded beaded panel designs was limited in scope, did not include all the panel variables and was based upon a very limited amount of experimental data. An improved design chart was developed based on a series of panel endurance tests and a semi-empirical approach utilizing Miles' single-degree-of-freedom random response equation to predict the dynamic stress combined with a finite element approach for determining natural frequencies and static stress values. A multiple regression technique was used to formulate the frequency and static stress equations using the computer generated data from the finite element models. These equations related the panel static stress and frequency to the panel geometric parameters. The finite element models were adjusted by using panel test data to give the calculated values close agreement to the measured values. The computer program was needed to give the additional panel data, not obtainable from the test program because of a lack of panel designs, required to develop the design chart. After the above expressions were obtained they were substituted into Miles' equation to formulate an equation to predict the mean square dynamic stress due to the acoustic load. The multiple regression technique was again used to regress the measured dynamic stress and acoustic load from the panel testing program against the above developed parameters to give a proportionality factor based upon test data. This final

equation was used in the design chart to predict stress. To obtain panel life, the S-N curve from the panel testing program was used as part of the design chart. The above procedure is detailed in Reference 6 and the final design chart is given in Figure 1.

Two programs are currently being conducted at the AFFDL to develop sonic fatigue data for bonded structure. The objective of the first effort is the development of sonic fatigue design data for bonded structural sections based on the skin-stringer-frame design commonly used in aircraft. The bonding spcification is an advanced process defined in Boeing Process Specification BAC-5555. The analytical and experimental program consists of the following:

(a) Limited analytical investigations to determine the basic dynamic characteristics of bonded multi-bay skin-stiffened structural designs.

(b) An experimental plan to develop test article designs consisting of beams and flat multi-bay panels. The beam specimens are being tested on a random shaker to derive basic random stress cycle data and the multi-bay panels are being tested in a high intensity noise environment to develop data that can be related back to the beam tests.

(c) Analysis and evaluation of test data combined with the theoretical results to develop the design technique.

The second program is similar with the exception of the bonding system which is a standard state-of-the-art metal bond etch cleaning process combined with a conventional adhesive. Data from the program will be used as a baseline for developing sonic fatigue criteria for bonded structures.

An effort to compare weldbonded stiffened skin structure with identical riveted structure, except for the joining method, is currently in progress at the AFFDL. Table II summarizes the test results. Failures occurred in the joint, support structure, or both. The weldbond failures were characterized by bond failure at the edge of the stiffener followed by a crack in the spot weld nugget. The spot weld crack grew, linking with other cracks to form larger cracks through the skin material. The sonic fatigue life of the weldbonded structures was generally equal to or less than that of the riveted structure.

Figure 2 shows the fatigue life characteristics of the weldbonded joint[7]. These data are adhesive failures for a spot weld etch surface preparation and a Class "B" Military Specification MIL-W-006858C spot weld. At high stress levels, the riveted joint has the better fatigue life. By extrapolation to low stress levels, it appears that the life of the weld-bonded joint will approximate that of the riveted joint. The stresses shown are skin stresses, although the failures obtained were adhesive failures. The quality and type of the bonding process used in the weldbonded structure has major significance in the fatigue life of the structure.

Northrop[8], has recently completed a fatigue test program with weldbonded aluminum beams subjected to shaker excitation with narrowband random input producing a resonant response. The fatigue data that was generated may be extrapolated and applied to the weldbonded structure of skin-rib-stringer type construction subjected to acoustic excitation.

Sonic testing and service experience have indicated the importance of the panel to rib, or panel to frame, joint. Preliminary analysis methods currently exist at Boeing to predict the sonic fatigue life of these joints. Further refinement and correlation with laboratory results appear desirable. Panel tests at Boeing have indicated the importance of stringer stiffness and detail design quality on fatigue life[9].

Considerable work has been done to establish sonic fatigue design parameters and allowables for mechanical fasteners along frames and ribs[5]. From this work, analysis techniques have been derived to evaluate the sonic fatigue problems during an airframe design program. However, similar work and testing is now required for advanced attachment techniques. Stress concentration effects under random flexural excitation for welds, bonds, and integral ribs should be derived in order to give sonic fatigue support to the designer.

Historically, corrosion in aircraft structure has been a source of structural problems. To alleviate these corrosion problems, Lockheed[5], has made efforts to replace the typical mechanical fastener for surface panel-to-frame attachments. This has led to studies of other attachment techniques such as spotwelding, weldbonding, improved structural bonds, etc., which do not require surface drilling.

A need exists for the development of high cycle random fatigue data and improved test capabilities for obtaining these data. A recent survey conducted by the AFFDL, Figure 3 of Reference 10, shows the scarcity of such data for aluminum alloys. A program was completed for AFFDL by Lockheed to develop high cycle random fatigue data and the design of an automatic test system to generate such data[11].

Two sets of coupon type cantilever beam fatigue specimens were tested. One set was 2024-T81 bare aluminum sheet riveted to a doubler of the same material. The other was 6AL-4V annealed titanium riveted to a doubler of the same material. The aluminum specimens were tested at 75°F and 250°F; the titanium at 74°F and 600°F. In both cases, high frequency (up to 950 Hz) resonance test techniques were employed, with multiple specimens (3 to 6 on a

shaker) at flexural strain levels consistent with fatigue failure over the range of 10^6 to 10^9 cycles. This series of tests resulted in four S-N curves given in Figure 4 as taken from Reference 11.

The governing requirements for the fatigue test system were established in the program and it was concluded that conventional electromagnetic shakers exciting multiple specimens at resonance was the preferred method for conducting the high cycle, random, reversed bending fatigue tests. Two alternate testing methods were investigated, one consisting of a single shaker with multiple specimens, the other consisting of multiple shakers with single or multiple specimens. The final design, presented in Reference 11, is an automatic, digitally controlled fatigue test facility, embodying five independent excitation subsystems suitable for continuous unattended operation. Figure 5 shows the control system for this test capability.

For the design of ducts carrying high velocity flow at elevated pressure and temperature, where sound and fluctuating pressures can induce flexural stresses, Lockheed[5], has a need for high cycle random fatigue data for the high temperature alloys, particularly stainless steels and Inconel. These design cases also involve long life, frequently upwards of 10^{10} cycles. Inlet and discharge ducts in the C-141, C-5A, and JetStar engine installations have also involved design to high cycle life, using conventional aluminum. The inlets and discharge ducts of various advanced designs such as the Advanced Medium STOL Transport (AMST), Quiet Short Haul Research Aircraft (QSRA), and Advanced Technology Transport (ATT) have required random flexural fatigue data for noise absorbent liner materials, primarily perforated sheet.

COMPOSITES

Sonic fatigue design criteria for composite materials are not yet available in comprehensive form. Present programs being conducted and planned in industry and the AFFDL concentrate on graphite epoxy materials.

Sonic fatigue experimental programs conducted at the AFFDL on flat boron-epoxy and graphite epoxy panels showed a tendency toward delamination in the matrix material and failures around surface penetrations for fasteners which were difficult to control. These problems stress the necessity for proper joint design. Some of these difficulties can be corrected by integral joints of skin and support structure. Many composite aircraft structures tested under service noise levels survived several lifetimes without serious damage signifying the basic superiority of these advanced materials from a sonic fatigue viewpoint.

Long term endurance tests on composite material aircraft components over a period of several lifetimes are in preparation at the AFFDL with the goal to determine the characteristics and progression of fatigue failures. A current program of this type involves a composite structure for the B-1 aircraft.

In several recent programs, Lockheed[5], has considered use of fiberglass and graphite composite structure in areas sensitive to sonic fatigue. Some examples are: C-130 flap skins and nacelle fairings; C-141 wheel wells and wing root fairings; NASA QSRA flaps and fairings; and B-1 slats. These cases have also revealed a need for high cycle random flexural fatigue data (S-N type) for this stiffened-skin structure made of

- plies of unidirectional graphite fibers in multiple directions,
- plies of bidirectional woven graphite fabric,
- plies of bidirectional woven fiberglass.

Preliminary tests have shown these materials to be very sensitive to fiber lay-up details, whereby tests of generalized configurations do not have broad application.

At Rohr Industries[12], testing has been completed and data are being used to develop a preliminary sonic fatigue design method. Various stiffened and unstiffened skin designs were tested. The effects of curvature, impact damage propagation and different boundary conditions were investigated. A full-scale test of a composite nacelle structure was carried out. Data are being compared to Progressive Wave Tube (PWT) data. Finite element computer studies are being used to form the analytical base for the design method. An in-service evaluation of the composite nacelle structure is currently in progress (200 flight hours have been accumulated). PWT data on graphite reinforced metal structures have also been obtained.

Large composite panels are usually used for wing to body fairings and other fairings. These glass/epoxy or graphite/epoxy structures consist of large panels, with minimum support structure, resulting in panels with low resonant frequency. Research is planned at Boeing[9], toward methods of predicting the sonic fatigue performance of these panels.

ADVANCED STRUCTURES AND ANALYSIS TECHNIQUES

Rohr Industries has tested twenty bonded aluminum panels in a PWT and finite element computer studies are in progress. The objective is to develop a sonic fatigue design method. Particular attention is being paid to the edge design parameters and their representation in finite element models. It was found that the sandwich core is not fully effective as the edge is approached. In order to qualify the degree of effectivity, detailed models representing core elements are

being used in conjunction with more coarse overall panel models to develop greater accuracy in predicting frequencies and stresses.

Computer studies and static tests are being used to optimize various honeycomb edge designs. Closure designs have been developed that equalize the stresses in the two facings at the panel edges. This is important in developing optimum sonic fatigue designs. Analysis and static testing of bonded overlap joints is also in progress. This work will be used to incorporate all important honeycomb closure design parameters into the curved sandwich panel design method.

One of the most recent series of tests conducted by Vought Corporation[13], has involved the sonic fatigue analysis and exposure of the reinforced carbon-carbon leading edge for the Space Shuttle. Development tests have been conducted on several full scale segments of approximately 2 foot span. These tests were conducted in a PWT contoured to suit the specimen. The speimen was mounted on four lugs designed for thermal expansion. A finite element routine was developed to predict the stresses at these lug mountings and laboratory tests confirmed the loads with respect to both frequency and amplitude within a range of 10 to 20 percent. This information is to be published shortly. This series of tests will continue and will include the Space Shuttle nose cap in the near future which will be tested under reverberant conditions.

Computer software techniques have been developed at the AFFDL to determine and display mode shapes of complicated structures. The theoretical considerations which form the basis for computer mode shape determination have been developed. In brief, the procedure involves measuring structural transfer functions consisting of acceleration output for a known impulsive force input. The force input or the acceleration response output can be fixed while the other varies in location. It is usually easier to vary the force input but, for best results, lightweight structures require a fixed input location.

The analyzed data can be displayed in several ways depending upon the requirements of the specific test. One output is the Nyquist plot (Real versus Imaginary Components), another is the Bode plot (Log Magnitude and Phase versus Frequency), a third representation is the real part and the imaginary part of the magnitude plotted versus frequency. The modal patterns are displayed in either of the two following ways. For visualizing the possible motions of the structure, animated mode shapes are displayed on a cathode ray tube. Plots of equal amplitude contours, for each of the various mode shapes can also be provided. This approach is more suitable for hard copy presentation. Figure 6 shows the block diagram for structural mode shape computation. In Figure 7 the 224 Hz and 320 Hz mode shapes for a composite material vertical stabilizer are presented. This is a typical example of modal analysis performed on a structural test specimen. The data were input to the computer system from a force transducer mounted on a hammer and a movable accelerometer mounted on the vertical stabilizer. The hammer was used to provide an impulsive force input at a fixed location of the structure.

A concept called "Intrinsic Structural Tuning" for optimizing the fuselage structure for sonic fatigue and cabin noise has been developed at Boeing[14]. According to this concept, the skin stress response and sound transmission through the skin can be minimized by tuning the skin panel frequency to the stringer frequency. Additional reductions can be obtained by applying damping treatment on the stringer flanges. The concept has been verified analytically[15]. For test verification, three five-bay skin-stringer models with three different stringer spacings were built. One of the panels was intrinsically tuned by using a 7½ inch stringer spacing. These panels were tested in the laboratory[16] and the concept was verified (Fig.8). These panels were also tested in the field, under a USAF/NASA contract, using the YC-14 engine-flap-wing test set up, and the field test results agreed with the laboratory test data. Thus the tuned structure concept holds a significant potential for improving the current sonic fatigue design technology. However, sonic fatigue testing for tuned and untuned skin-stringer panels will be necessary to establish the actual improvement in the sonic fatigue life.

Several experimental programs have been completed at the AFFDL to evaluate honeycomb test panels made of both titanium and stainless steel to evaluate their application in a high temperature sonic environment. Two fabrication techniques were involved, one of welded construction the other brazed. In all cases, the stainless specimens either did not survive their design environment (170 dB O/A SPL, 900°F) for the prescribed period of time, 50 hours, or were at best marginal in performance. Consequently, it was recommended that additional high temperature sonic fatigue tests be conducted on stainless steel honeycomb panels designed to withstand a more severe acoustic environment. The titanium specimens, in a less severe environment (158 dB o/A SPL, 500°F), were rated as acceptable. However, the above results were qualified by a limited number of test samples. Due to the above, a series of stainless steel panels, both brazed and welded, and of different core heights were designed for increased sonic fatigue resistivity at high temperatures and are being tested. A production engine fairing of brazed titanium honeycomb will be tested in a specially designed fixture in an environment that is based upon measured operational data. The prescribed test interval will be equivalent to the total "most severe" exposure time accumulated during the projected service life of the aircraft.

SHORT TAKE-OFF AND LANDING (STOL) AIRCRAFT STRUCTURES

The bypass flow in the CF6-50 engines to be used for YC-14 causes a static pressure differential across the nacelle structure[9]. The outer cowl experiences tensile loads while the inner cowl experiences compressive loads. The spectrum of the internal turbulence level reaches a peak at the fan tone at 2000 Hz, and the spectrum level decreases toward the low frequency end. The AGARD Acoustic Fatigue Design Procedures are not applicable to this situation, since they apply

only to fuselage skin panel vibrations excited by jet noise at take-off and the effect of any internal or external pressure differential is not taken into account. Therefore, a group of curved, stiffened panels, simulating YC-14 propulsion structure is being subjected to a static pressure differential and tested for sonic fatigue life in the Boeing sonic fatigue laboratory. The data from this test will be combined with analytical predictions based on a finite element method, to develop an improved sonic fatigue design procedure which will include the effect of in-plane loads.

In the case of the core cowl, radiant heat from the engine produces temperatures above 300°F on the aluminum structure. Hence, the effect of heating, hoop compression loads, and fan duct noise are all combined on the core cowl structure. Analysis and testing will be directed toward this problem. Structure aft of the engine experiences noise and heat during taxi and take-off conditions when aircraft velocity is low and air flow over the structure cannot significantly reduce the heating. Future analysis and testing of this problem are planned.

SYSTEMS ANALYSIS AND TESTING

Northrop[8], is evaluating pressure and accelerometer experimental data obtained during tests on a vertical stabilizer of the YF-17 aircraft because of the knowledge of a high intensity vibroacoustic environment under certain flight conditions. Using these data, Northrop plans to develop structural design guidelines (in particular, for the F-18 aircraft) for structural components in the area of concern.

Ground and flight tests have been performed and considerable acoustic response data have been obtained by Rohr Industries[12]. Instrumented structures included aluminum honeycomb, skin-stringer and titanium nacelle panels. Testing was carried out with and without anti-icing systems operating in order to evaluate temperature and pressure combined loading effects.

At Vought Corporation a series of full scale sonic fatigue tests on an engine inlet, using the engine as a forcing function, was performed. Element tests on axial segments were conducted on a shaker. These tests are described in Reference 17. Subsequently the entire inlet was installed in the Acoustics Laboratory and a progressive wave applied to a segment approximately 14 degrees wide. The multiple-pure-tone forcing function was simulated between 800 and 1200 Hz by two Ling EPT-200 transducers at levels equivalent to full scale. The total spectrum could not be simulated due to lack of acoustic power. Failures were not duplicated, leaving the conclusion that multi-mode interaction was necessary in order to duplicate field failures.

SUMMARY OF PROPOSED WORK

Table III summarizes some of the subjects proposed for near term R&D programs. In our opinion development of high cycle material and joint fatigue data should be given the highest priority since this basic information is generally not available and is urgently needed for all future design chart development. Initially a review of existing data within the NATO countries should be conducted and serve as a basis for planning of future efforts.

The problem of establishing accelerated testing techniques could also be undertaken on a cooperative basis. Acquisition of sonic fatigue test data with load cycles above 10^6 is a time consuming expensive process which in many cases cannot be carried out to the number of cycles required for the life of the aircraft. Frequently over design results with weight penalties not acceptable in high performance aircraft. The recent trend to prototype aircraft procurement has resulted in assumptions for structural performance based on the brief prototype flying time which are not applicable to qualification for sonic fatigue life of structure. Full qualification of the production type aircraft structure is still required.

Many of the proposed programs listed are an extension to work conducted in the past and are the result of present structural optimization efforts. The nature of these efforts is largely preventative to avoid a recurrence of costly maintenance and retrofit problems.

In the area of load criteria, efforts should be concentrated on near field noise prediction methods and measurements on high lift devices, two-dimensional nozzles and high speed flow noise sources. The optimum sonic fatigue design of fuselage structures, strut fairings, access doors and tail structures and flaps would be made possible through these efforts.

CONCLUSIONS

The brief summary of recent and current work in sonic fatigue given in the paper should be considered only representative of efforts in progress. The present state of relative freedom from sonic fatigue problems on aircraft must be directly attributed to the extensive work conducted in the past which resulted in widely applied design data and principles which materially reduced this costly problem. In order to maintain and further improve the state of the art, a continuing effort is needed. A well coordinated cooperative program will be well worth the effort in reducing future problems. It is suggested that a definitive program for future work be considered with the apportionment of tasks according to existing capabilities within the working group.

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TABLE I

Survey of Recent and Current Efforts in Sonic Fatigue in Government and Industry

Sonic Fatigue Program	*Laboratory or Company* A	B	C	D	E	F
Load Criteria	X	X		X		
Materia, Structure and Joint Data	X	X		X		
Composites	X	X	X		X	X
Advanced Structures and Analysis Techniques	X	X	X		X	
STOL Structures	X	X	X			
Systems Analysis and Testing	X	X	X	X	X	X

TABLE II

Comparison of Failures Weldbond vs Riveted Structure

Wedbond			*Riveted*		
Spectrum Level dB	*Joint-hours to Failure*	*Substructure-hours to Failure*	*Spectrum Level* dB	*Joint-hours to Failure*	*Substructure-hours to Failure*
122	144	144	121	26	26
125		45	125		59
128	2.5		128	47	
131	1.0		132		6.8
131	5.0		131	8.0	
129	123		128		339
132	1.5		132	1.8	
132	1.0		132	1.0	

TABLE III

Summary of Projected Sonic Fatigue Research and Development Requirements

LOAD CRITERIA

Noise Prediction Methods for Impinging Jets

STRUCTURAL

- High Cycle Material and Joint Fatigue Data
- Composite Structure Sonic Fatigue Design Criteria
- Sonic Fatigue Design Criteria for Curved Nacelle and Fuselage Structures with Differential Pressures
- Bonded Structure Sonic Fatigue Design Criteria
- Compound Structure (Sandwich Design) Design Criteria
- Determination of Sonic Fatigue Life of Structure Under Combined Static, Thermal and Dynamic Loads
- Stress Concentration Effects Under High Cycle Random Loads
- Structural Optimization Under Consideration of Selective Damping Application
- Crack Propagation

TESTING TECHNIQUES AND INSTRUMENTATION

- Accelerated Testing Methods
- High Temp Strain Measuring Techniques
- Fatigue Detection Techniques, Crack Propagation and Subsurface Fatigue Detection

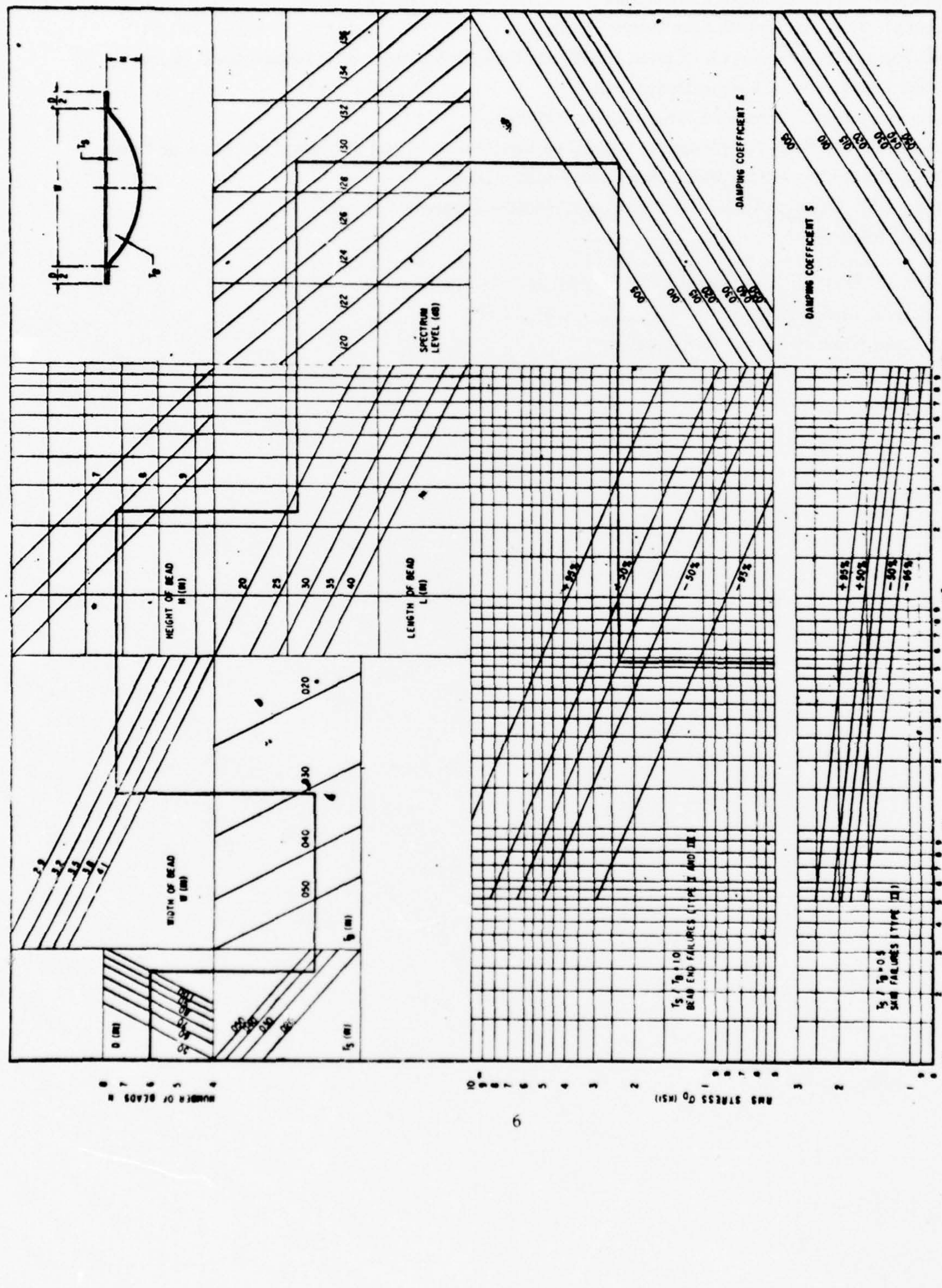
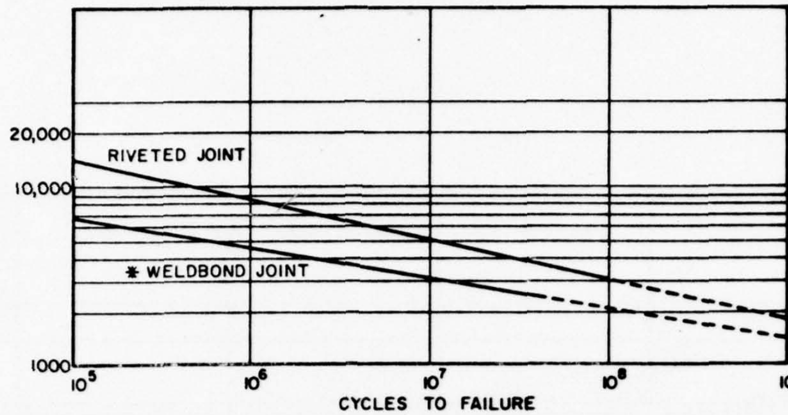


Fig.1 Design chart for bonded beaded panels



* Spot weld etch, class "B" spot weld
(adhesive failure shown)

Fig.2 Comparison of weldbonded vs riveted construction

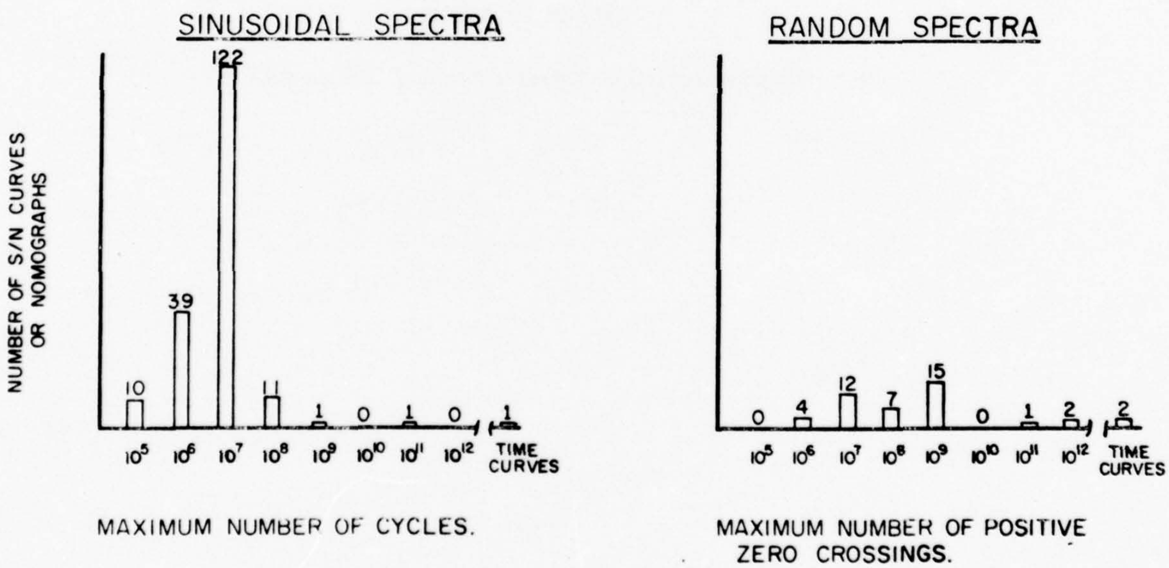


Fig.3 Fatigue life data for aluminum alloys, tested with sinusoidal and random spectra of vibrations

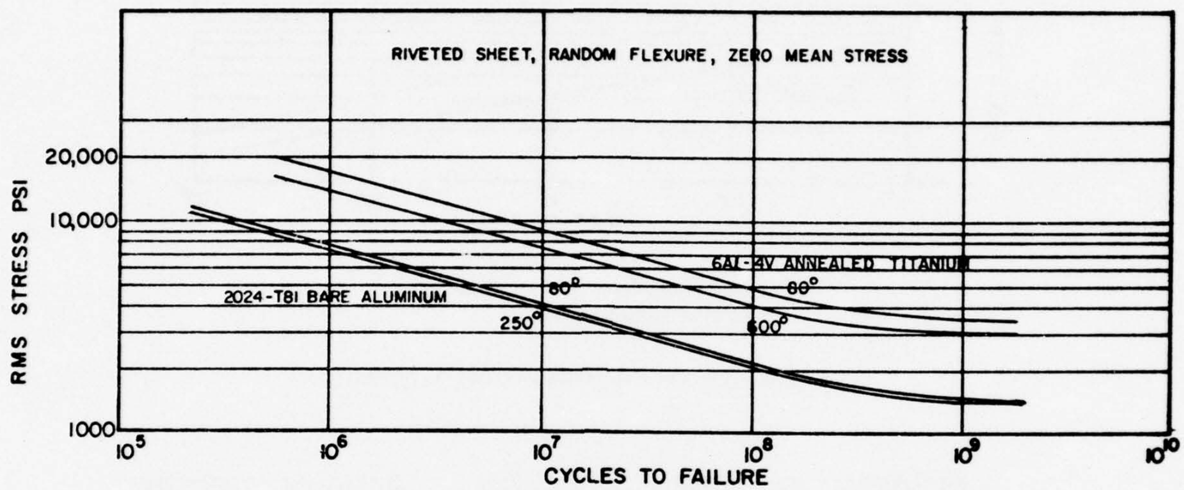


Fig.4 Comparison of fatigue curves for aluminum and titanium

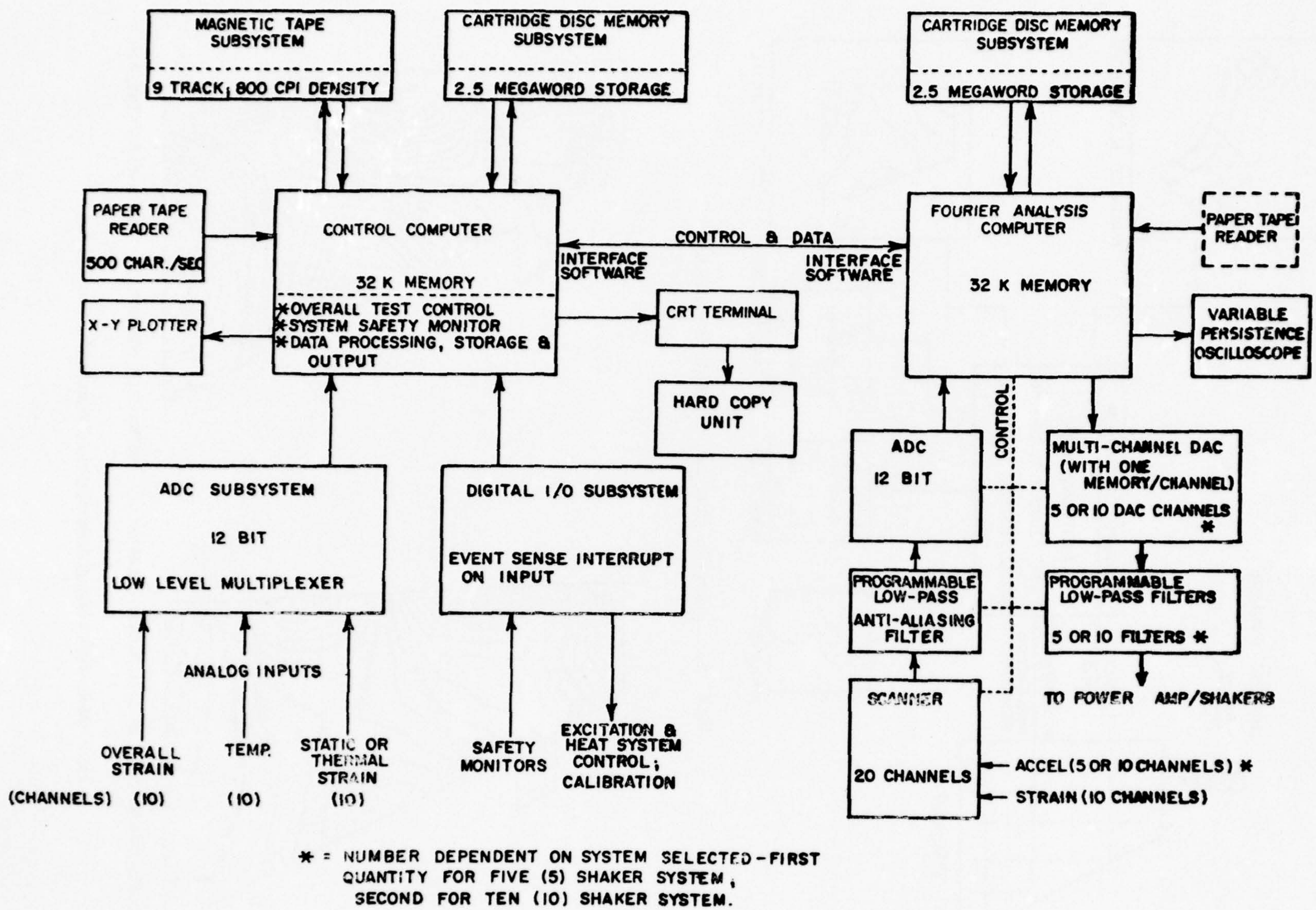


Fig.5 Multi-shaker facility control system

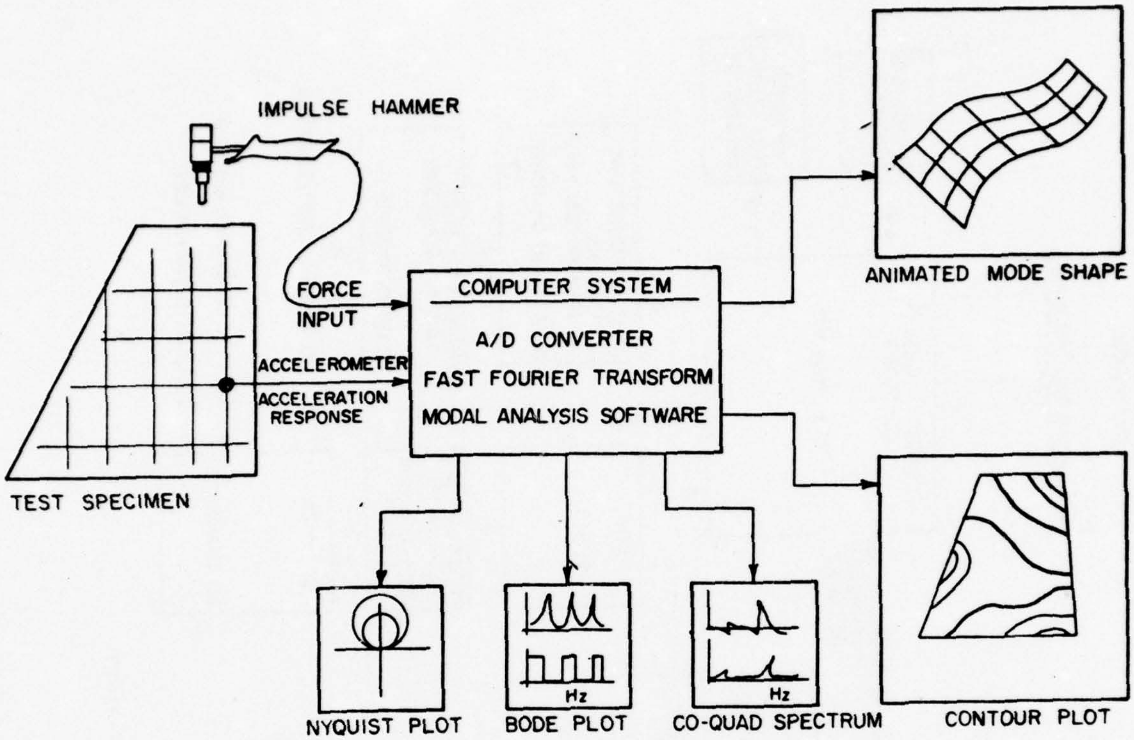


Fig.6 Block diagram for structural mode shape computation

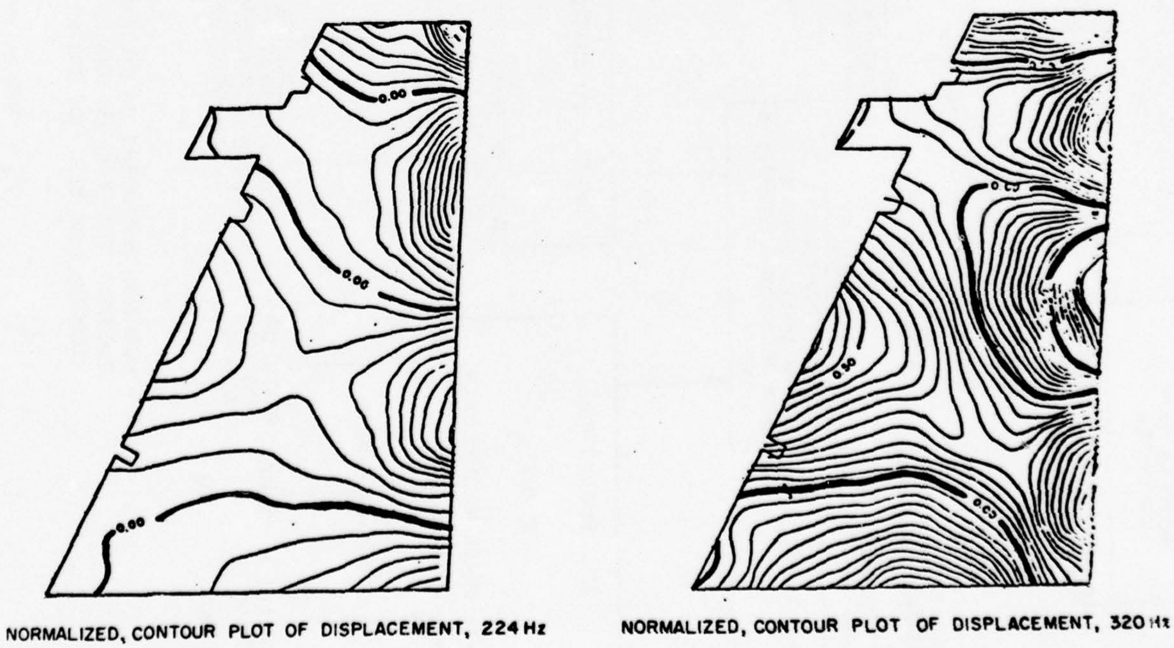
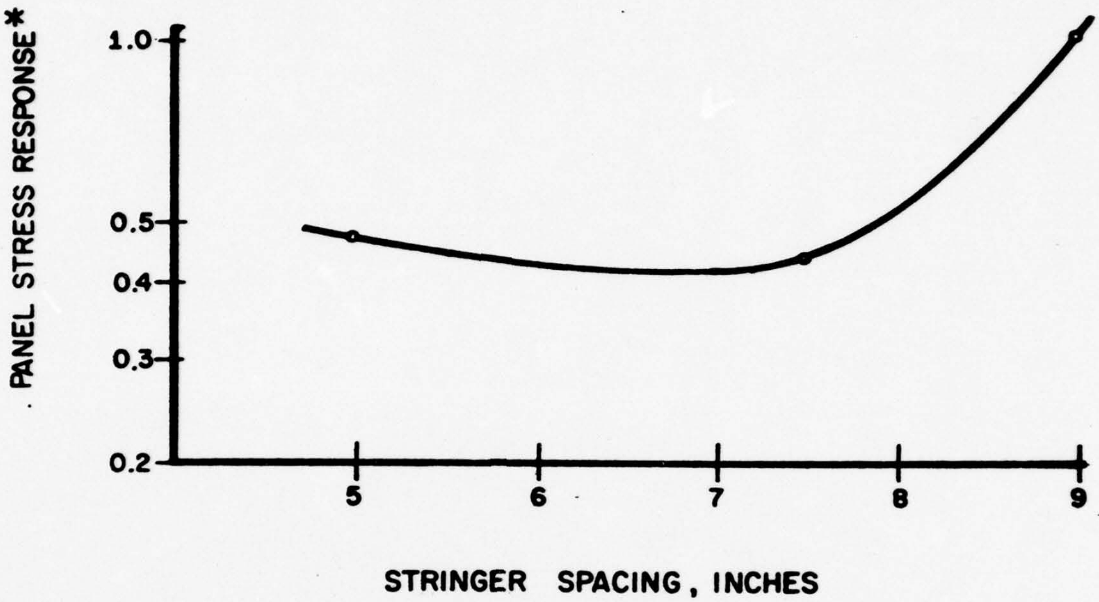


Fig.7 Mode shapes of experimental composite material aircraft structure



(* Normalized with respect to the panel with 9 inch stringer spacing.)

Fig.8 Reduction of maximum skin stress by intrinsic structural tuning

SOLUTION EXPERIMENTALE DE PROBLEMES DE FATIGUE ACOUSTIQUE

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SOMMAIRE

Deux problèmes sont présentés dans cet exposé:

Le premier est une étude de structure composite réalisée au stage projet. Elle consiste à définir la tenue d'éprouvettes en fibres à haut module et à la comparer à celle d'éprouvettes en "nida alliage léger" et "nida acier".

A partir des résultats obtenus sur ces éprouvettes et de l'analyse des mesures enregistrées au cours d'un essai de réponse sur une gouverne en fibres de carbone, la tenue à la fatigue sonique de cette gouverne est estimée.

Le deuxième problème, plus concret, résulte de dommages initiés en vol sur des carénages de servocommandes de gouverne d'un avion en exploitation. L'étude a pour but de définir et de justifier une carène de remplacement, présentant de bonnes garanties d'endurance.

PROBLEM No.1: ETUDE STRUCTURE COMPOSITE

Caractéristiques des éléments étudiés (voir pl.1)

Quatre caissons ont été étudiés:

- un caisson en nida alliage léger, constitué de deux panneaux nida sandwich reliés entr'eux par des âmes de bordure en structure conventionnelle. (Masse: 15,700 Kg).
- un caisson en nida acier, de même principe constructif que le précédent. (Masse: 20,700 Kg).
- un caisson en fibre de carbone, constitué de six panneaux sandwich à âme Nomex et à revêtement en fibre de carbone. (Masse: 11,200 Kg).
- un caisson en fibre de bore, de même conception structurale que celui en fibre de carbone mais à revêtement de bore.

Bien que ces caissons soient de forme et de dimensions identiques, une différence fondamentale inhérente à la conception des bordures existe entre les caissons en fibres à haut module et ceux en nida.

- une gouverne en fibres de carbone, de même géométrie que celle de l'avion étudié. De conception monolithique, elle comprend des revêtements en composite fibre de carbone, résine et un remplissage en nida Nomex.

Presentation des Essais (voir planche 2)

Les essais peuvent être divisés en deux parties:

- Une première partie dans laquelle les quatre caissons sont soumis successivement à:
  - un essai de résonance sous excitation sinusoïdale,
  - un essai de réponse sous excitation aléatoire,
  - un essai d'endurance sous excitation aléatoire.
- Une deuxième partie dans laquelle la gouverne est soumise à un essai de résonance et de réponse. L'analyse des résultats obtenus au cours de ces deux parties permet:
  - une comparaison des caractéristiques dynamiques des éléments étudiés,
  - une estimation de la tenue à la fatigue acoustique des caissons en fibres à haut module,
  - une estimation de la tenue à la fatigue de la gouverne en fibres de carbone.

Les essais de résonance sont effectués sous une excitation sinusoïdale d'intensité constante. Pour les essais de réponse et d'endurance, le spectre d'excitation est similaire à celui d'un réacteur simple flux. Il se caractérise par un niveau sensiblement constant dans la gamme de fréquences comprise entre 150 et 750 Hz.

Les niveaux globaux de pressions sonores sont de:

- 158 dB, pour une première phase de 100 heures,
- 164 dB, pour les essais effectués après ces 100 heures.

Ces dernières conditions volontairement destructives, sont très sévères. 164 dB correspondent à ce qui peut être rencontré très localement sur certains avions lors des points fixes au régime maximum. Par exemple, pour les avions de la nouvelle génération, équipés de réacteurs double flux, les niveaux de bruit maximums estimés sur les structures, sont de l'ordre de 145 dB.

Analyse des Resultats: 1ère Partie (voir planche 3)

Cette analyse est basée sur les valeurs enregistrées à l'aide des jauges les plus caractéristiques collées sur les caissons.

La jauge A est collée sur la périphérie des panneaux, perpendiculairement aux cornières de bordure.

La jauge B est collée au centre des panneaux, parallèlement au petit côté.

Les modules d'élasticité des matériaux composites varient en fonction de leur composition. Pour permettre une comparaison plus facile avec les structures en "nida", les mesures de jauges sont exprimées en $\frac{\Delta l}{l} 10^{-6}$.

Essai de résonance:

Les quatre types de caisson ont des spectres de réponse très voisins, compris entre 200 et 1200 Hz et une nombre d'harmoniques sensiblement identiques.

Les fréquences fondamentales des caissons en fibres de bore et de carbone sont légèrement plus faibles que celles des caissons "nida":

F = 240 Hz pour le caisson en carbone,
F = 283 Hz pour le caisson en bore,
F = 372 Hz pour le caisson en alliage léger,
F = 386 Hz pour le caisson en nida acier.

Essais de réponse:

Ils ont montré que pour un même niveau de bruit et une même position des jauges:

- les allongements sur les panneaux en fibres à haut module sont, en moyenne, du même ordre que sur les panneaux en nida, avec cependant des pointes importantes au niveau des bordures,
- sur les panneaux en fibres à haut module, les allongements au voisinage de la jonction panneaux, âmes de bordure, sont très supérieurs à ceux mesurés au centre des panneaux.

Essais d'endurance:

Les essais sont résumés par le tableau ci-dessous:

	Niveau d'excitation					
	158 dB			164 dB		
	heure d' essai	$\frac{\Delta l}{l} 10^{-6}$ max	dommage	heure d' essai	$\frac{\Delta l}{l} 10^{-6}$ max	dommage
Nida Acier	100	30	néant	30	50	Détérioration des panneaux de bordure en structure conventionnelle
Nida alliage léger	100	20	néant	19h 30	35	Détérioration des panneaux de bordure en structure conventionnelle
Fibres de bore	100	300	néant	2h 10	550	"Eclatement" des grands panneaux
Fibres de carbone	100	450	néant	3h 30	800	Décollement nida revêtement sur un panneau de bordure

Ces essais effectués sur une seule éprouvette de chaque type, ne permettent que des conclusions prudentes. Cependant, les remarques suivantes peuvent êtres faites:

- le comportement dynamique des structures à haut module essayées, est équivalent à celui des structures nida,
- les ruptures constatées au cours des essais se sont produites sous 164 dB, niveau d'excitation particulièrement élevé.

Elles ne mettent pas en cause la tenue spécifique des matériaux étudiés:

– sur les caissons à haut module, les ruptures sont imputables à des flexions secondaires au niveau des jonctions panneaux-bordures,

– sur les caissons en nida, les dommages se sont produits sur les panneaux de bordures de conception conventionnelle.

Avec le dessin et l'échantillonnage de ces éprouvettes, les structures en fibres de bore et de carbon peuvent être garanties à des sollicitations acoustiques de l'ordre de 146 dB global et de spectre sensiblement identique à celui adopté pour ces essais.

Ceci, en admettant (pl.4 et 5):

(a) la limite de non rupture des éprouvettes essayées à 158 dB, soit des allongements RMS de:

$$255\,10^{-6}\ \frac{\Delta l}{l}\ \text{sur le caisson en bore}$$

$$500\,10^{-6}\ \frac{\Delta l}{l}\ \text{sur le caisson en carbone}$$

(b) une évolution des allongements identiques à celle représentée sur les planches 4 et 5.

(c) un coefficient de sécurité de 3, soit des allongements admissibles en toute sécurité de:

$$\frac{225\,10^{-6}}{3}\ \frac{\Delta l}{l}\ \text{pour le caisson en bore}$$

$$\frac{500\,10^{-6}}{3}\ \frac{\Delta l}{l}\ \text{pour le caisson carbone}$$

Il est certain que des sollicitations acoustiques de niveaux supérieurs pourraient être justifiées sur des structures à haut module:

(a) avec des structures "sandwich" dont les jonctions et bordures seraient améliorées,

(b) avec des éléments de remplissage: Nomex intégral.

D'autre part, plusieurs éprouvettes de chaque type permettraient une étude de la dispersion. Le coefficient de 3 pourrait être ainsi diminué. C'est ce qui fait l'objet d'études actuellement en cours.

Analyse des Resultats: 2ème Partie

Sur le caisson, les allongements sont maximums au niveau des jonctions des panneaux sandwich.

Sur la gouverne, la *répartition des niveaux est homogène sur toute sa surface.*

Les rapports sous 156 dB des allongements RMS maximums, relevés respectivement au centre et sur les bordures de ces éléments, sont les suivants:

$$\text{– sur les bordures: } \frac{\frac{\Delta l}{l}\ \text{caisson}}{\frac{\Delta l}{l}\ \text{gouverne}} = \frac{430}{28} = 15{,}3$$

$$\text{– au centre: } \frac{\frac{\Delta l}{l}\ \text{caisson}}{\frac{\Delta l}{l}\ \text{gouverne}} = \frac{115}{71} = 1{,}6\,.$$

Ces rapports montrent clairement l'influence du principe de jonction sur la réponse aux sollicitation acoustiques.

Discussion (planche 6)

La tenue en endurance de la gouverne a pu être estimée comme suit: l'évolution des allongements maximums relevés sur la gouverne est portée sur la planche 6. Elle montre que l'allongement de $\frac{\Delta l}{l} = \frac{500^{10^{-6}}}{3}$ est atteint par extrapolation de la courbe pour un niveau de bruit global de 164 dB.

Sur l'avion auquel est destiné le type de gouverne étudié, le niveau de bruit global maximum est de l'ordre de 156 dB. A ce niveau correspond un allongement RMS maximum de $70^{10^{-6}}$ soit, par rapport à la limite de non rupture définie pour le caisson en carbone, un coefficient de sécurité de $\frac{500}{70} = 7$ environ.

PROBLEME No.2: CARENAGE DE SERVO–COMMANDES

Sur des avions, de même type, en exploitation, des criques ont été initiées sur des carénages de servo-commandes de gouvernes, après un petit nombre de vols. Bien que les carénages soient des éléments secondaires et que ces dommages ne présentent aucun caractère de gravité, une étude a été entreprise pour trouver une solution à ce problème.

Le principe de cette étude peut être représenté par le tableau synoptique ci-après (vour planche 7).

Une premiére phase a consisté:

(a) à définir par des mesures en vol, les contraintes RMS et le spectre de réponse des carénages,

(b) à reproduire à la sirène sur une carène identique à celle de l'avion, les réponses dynamiques, en niveau et en spectre, ainsi que les dommages rencontrés en exploitation,

(c) à définir une équivalence heures d'essais ⟶ heures de vol.

Une deuxième phase a permis de vérifier par un essai d'endurance à la sirène, la validité des modifications apportées à une deuxième carène. Les conditions d'essais étaient identiques à celles de la première phase.

Une troisième phase, sur une carène de conception différente, a été rendue nécessaire par le fait que les résultats obtenus au cours de la deuxième phase ne présentaient pas toutes les garanties d'une tenue à la fatigue acoustique pendant une durée équivalente à la vie de l'avion.

Caractèristiques des Eléments Etudiés (planche 8)

Carène initiale:

Ce carénage est essentiellement constitué par une tôle de e = 3 mm en AU2GN, formée puis usinée chimiquement pour obtenir des fonds de mailles de e = 0,8 mm et des raidisseurs de h = 3 mm .

Carène renforcée:

Ce carénage de conception identique à la version initiale comporte tous les deux raidisseurs, un renforcement constitué par des arceaux de e = 1 mm en forme de ⊔. Des cales collées sur le fond de maille donnent une bonne assise au ⊔. Un film de viton est intercalé entre le ⊔ et les éléments sous-adjacents. La liaison ⊔ – carène est assurée par deux rangées de rivets.

Carène nouvelle définition:

Elle est constituée par une tôle laminée de e = 1,4 mm, formée au profil de la carène. Un renfort au bord festonné est collé sur la carène au niveau de ses fixations sur la structure.

Resume des Essais

Mesures en vol

L'enregistrement des contraintes dynamiques pendant toutes les phases d'un vol et leur analyse, ont permis de déterminer que:

- les contraintes sont maximales pendant le décollage, la montée initiale et le reverse à l'atterrissage,
- les spectres de réponse présentent des pointes très nettes entre 120 et 350 Hz,
- les contraintes maximales enregistrées sont de
  - 2,5 hb RMS sur le talon des raidisseurs,
  - 1 hb RMS sur la face interne du revêtement.

Essais d'endurance

Les conditions de vol ont été reproduites par la "sirène" avec un niveau global d'excitation de 148 dB. Valeur qui a servie de base au essais résumés par le tableau ci-dessous:

	Essai sous 148 dB			Essai sous 156 dB		
	heures effectuées	σ RMS max	dommages	heures effectuées	σ RMS max	dommages
Carène initiale	4	3,5 hb	identique à ceux detectés sur avion	/	/	/
Carène renforcée	50	1 hb	néant	16	2,2	identiques à ceux détectés sur avion
Carène nouvelle conception	50	1 hb	néant	50	2,3	néant

Estimation de la Tenue en Fatigue Acoustique

Cette estimation peut être établie en prenant pour base les valeurs du tableau du paragraphe précendent et en admettant l'hypothèse que les dommages constatés sur avion après 52 vols sont reproduits par:

(1) 4 heures d'essais à la sirène sous 148 dB, d'où 1 heure d'essais sous 148 dB = 13 vols;

En partant de ces bases et de cette hypothèse, la tenue en fatigue de la carène renforcée et de la carène nouvelle définition peut être établie comme suite.

(2) Nombre d'heures réalisé sous 148 dB = 50 heures.

(3) Relation entre les endommagements sous 148 dB et ceux sous 156 dB:

Cette relation s'établit à partir de courbe de fatigue sous excitation aléatoire de structure en alliage léger.

Cette courbe représentée en échelle log-log se traduit par une droite qui peut être extrapolée dans le domaine des faibles contraintes.

A une contrainte σ_1, équivalente à celle mesurée sous 148 dB, correspond un numbre de cycles N_1 ou un temps t_1.

A une contrainte σ_2, équivalente à celle mesurée sous 156 dB, correspond un nombre de cycles N_2 ou un temps t_2.

La relation $\frac{\sigma_2}{\sigma_1} = f\left(\frac{t_1}{t_2}\right)$ est vérifiée quand $\frac{\sigma_2}{\sigma_1}$ est affecté d'un exposant α.

La valeur de cet exposant varie sensiblement d'une courbe à l'autre. Sa valeur peut être prise égale à 7.

De la relation $\frac{\sigma_2^\alpha}{\sigma_1^\alpha} = \frac{t_1}{t_2}$ découle $t_1 = \frac{\sigma_2^\alpha t_2}{\sigma_1^\alpha}$ qui donne le nombre d'heures d'essais à 148 dB équivalent au nombre d'heures d'essais à 156 dB.

Ce qui donne, avec les valeurs du tableau précédent, environ 13.000 vols justifiés pour la carène renforcée soit à peu près la moitié de la durée de vie d'un avion, et, environ 163.000 vols justifiés pour la carène nouvelle définition, soit à peu près six fois la vie d'un avion. Ce coefficient laisse une large place à la dispersion.

(4) *Analyse et discussion des résultats* (voir planche 9)

La carène initiale a été dessinée avec le souci d'obtenir une rigidité maximum pour une masse minimum, c'est ce qui a conduit à cette conception de nervurage par usinage chimique. Raidisseur h = 3 mm, fond de maille e = 0,8 mm. Ce genre de dessin conduit bien entendu à un déport de la fibre neutre par rapport à la périphérie de la structure, d'où, sous l'effet des phénomènes de flexions alternées dues à la réponse dynamique de la carène, des allongements plus importants sur les talons des raidisseurs que sur les faces externes. Dans ce cas, précis, le rapport était de 3,5/1.

A la suite des dommages constatés sur avion, compte tenu de l'analyse précédente et dans le but de permettre l'utilisation des carènes déjà réalisées, la solution de renforcement fut envisagée. Elle permit, moyennant une

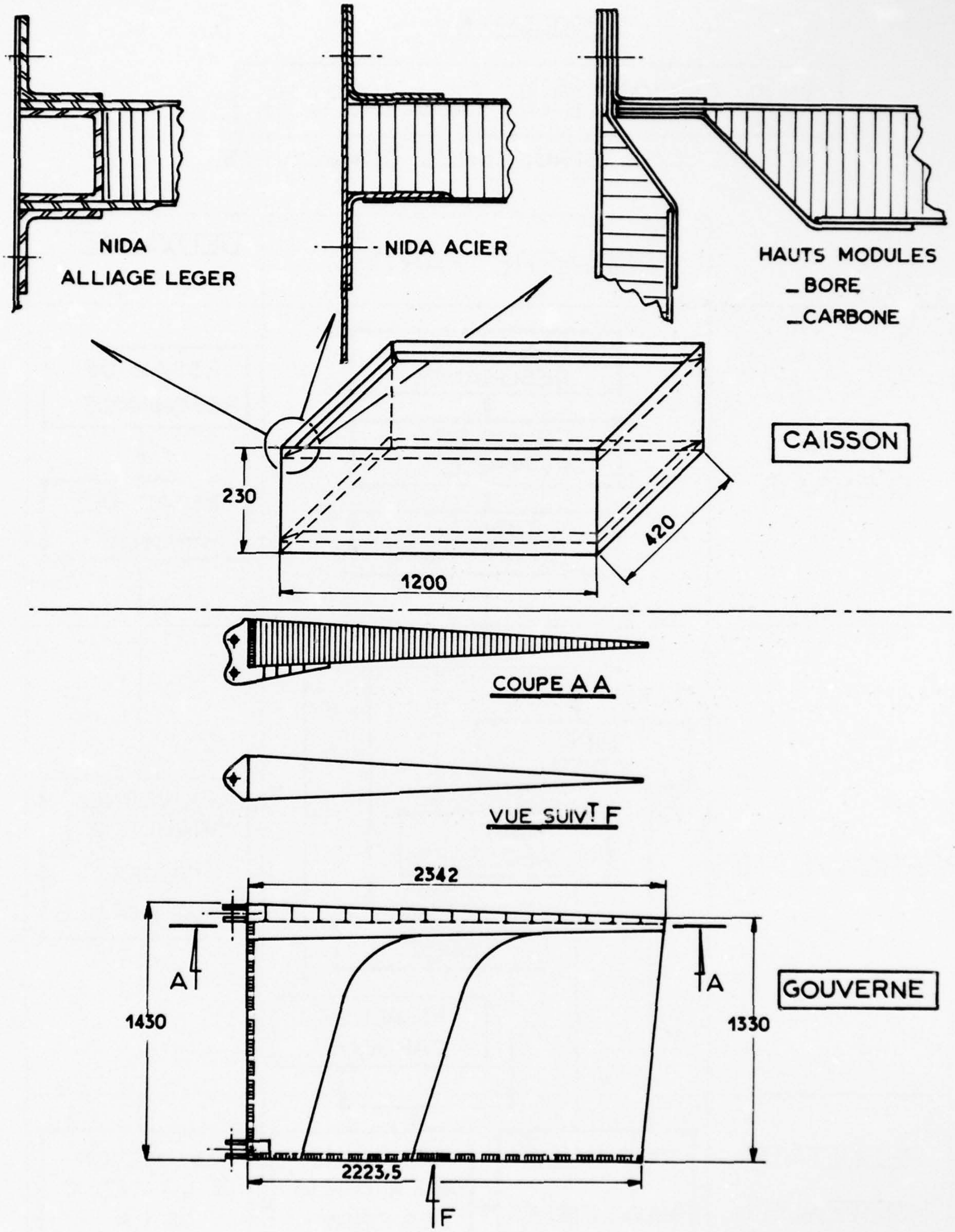
augmentation de masse de 40%, d'obtenir une rigidité telle que les contraintes dynamiques maximales auraient dû être ramenées à un niveau garantissant la tenue à la fatigue acoustique des carènes.

Bien que ces conditions fussent réalisées (1 hb RMS sous 148 dB, 2,2 hb RMS sous 156), des dommages furent initiés. Ceci incita à une étude plus approfondie du phénomène; en particulier, un examen micrographique des zones endommagées montra un profil d'usinage chimique fortement dentelé, propice à l'initiation de criques.

C'est pourquoi, la carène nouvelle définition fut conçue en essayant de réduire les defauts constatés sur les deux précédentes.

La solution tôle laminée e = 1,4 mm, formée, fut retenue. Cette épaisseur donna une rigidité équivalent à celle de la carène initiale avec une masse légèrement inférieure à celle de la carène renforcée. Les contraintes maximales d'une niveau identique à celui de la carène renforcée, permirent, compte tenu du bon état de surface, une parfaite tenue aux sollicitations acoustiques imposées.

Cette étude, d'un cas concret, montre comment un élément qui répond parfaitement aux critères d'une bonne tenue aux efforts généraux, peut présenter des failles sérieuses quant à son bon comportement à la fatigue acoustique, failles qui sont principalement dues à une optimisation difficile de la hauteur des raidisseurs et à un mauvais état de surface inhérent à l'usinage chimique. Ce procédé de fabrication doit être déconseillé pour les structures de faible épaisseur soumise à des sollicitations dynamiques importantes. D'ailleurs, comme on l'a vu, des solutions très simples peuvent donner dans certains cas des résultats nettement meilleurs que des solutions plus élaborées et plus onéreuses.



PROBLEME N°1

SCHEMA DES EPROUVETTES

Planche 1

PROBLEME N°1

VUE SYNOPTIQUE DES ESSAIS

ETUDE DES STRUCTURES COMPOSITES

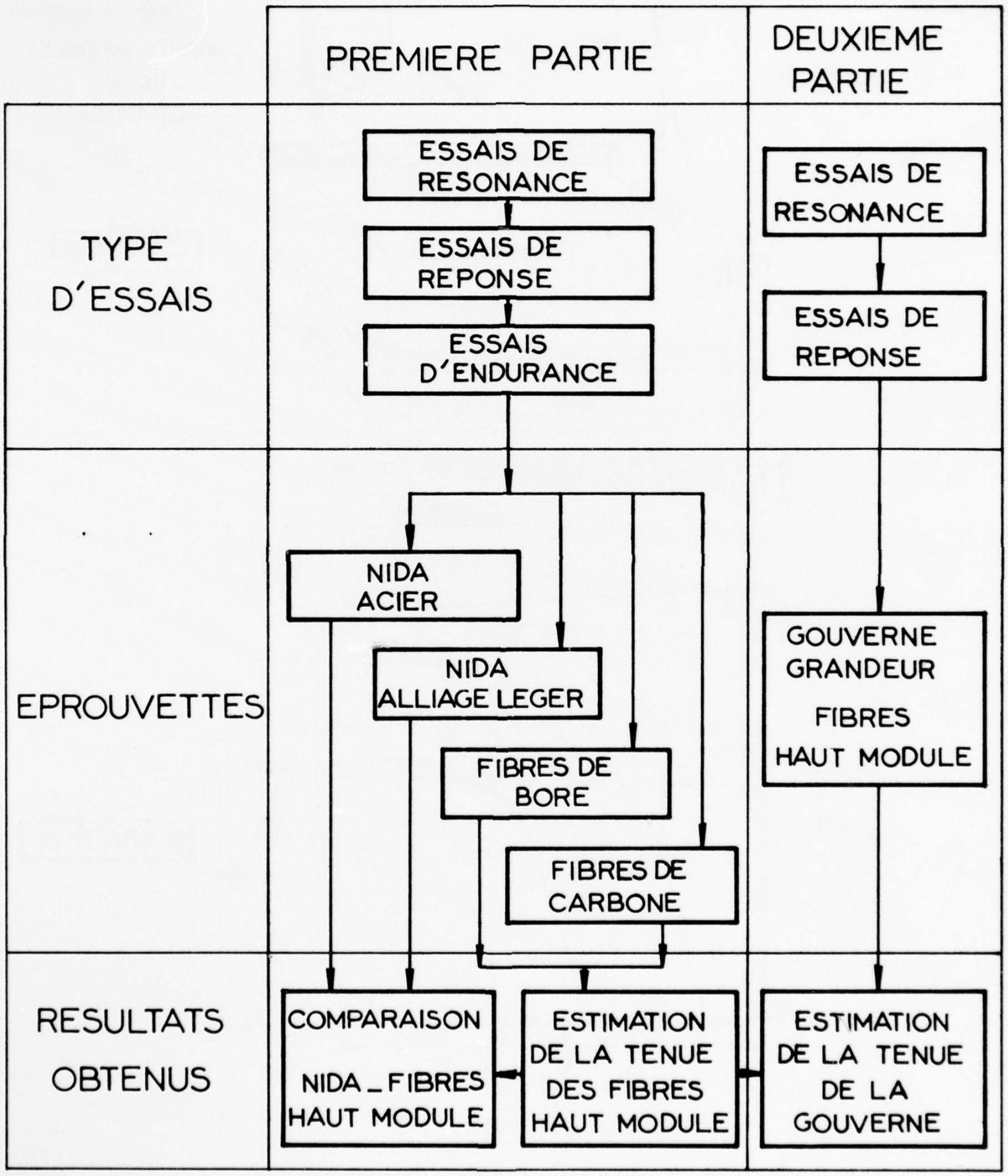
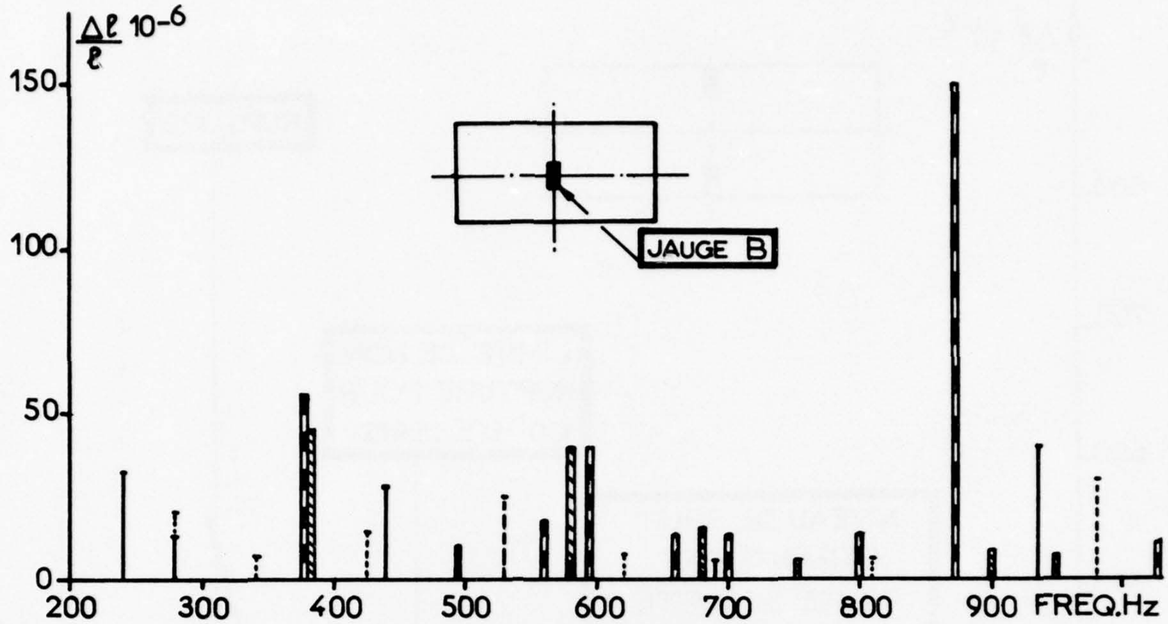
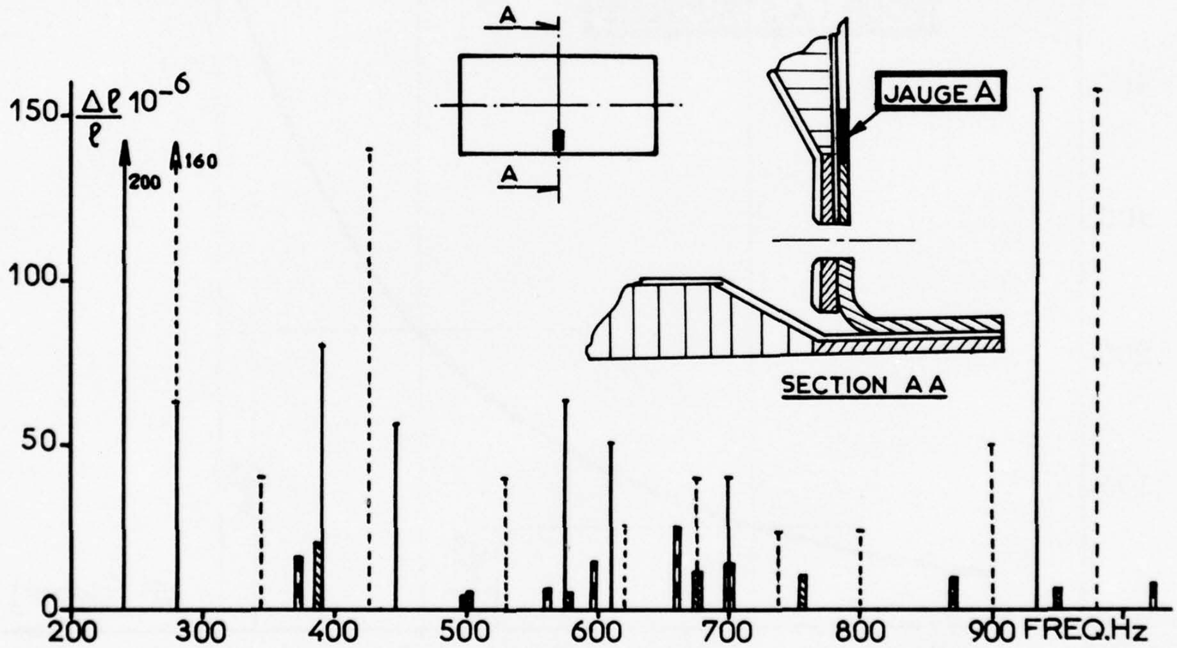


Planche 2



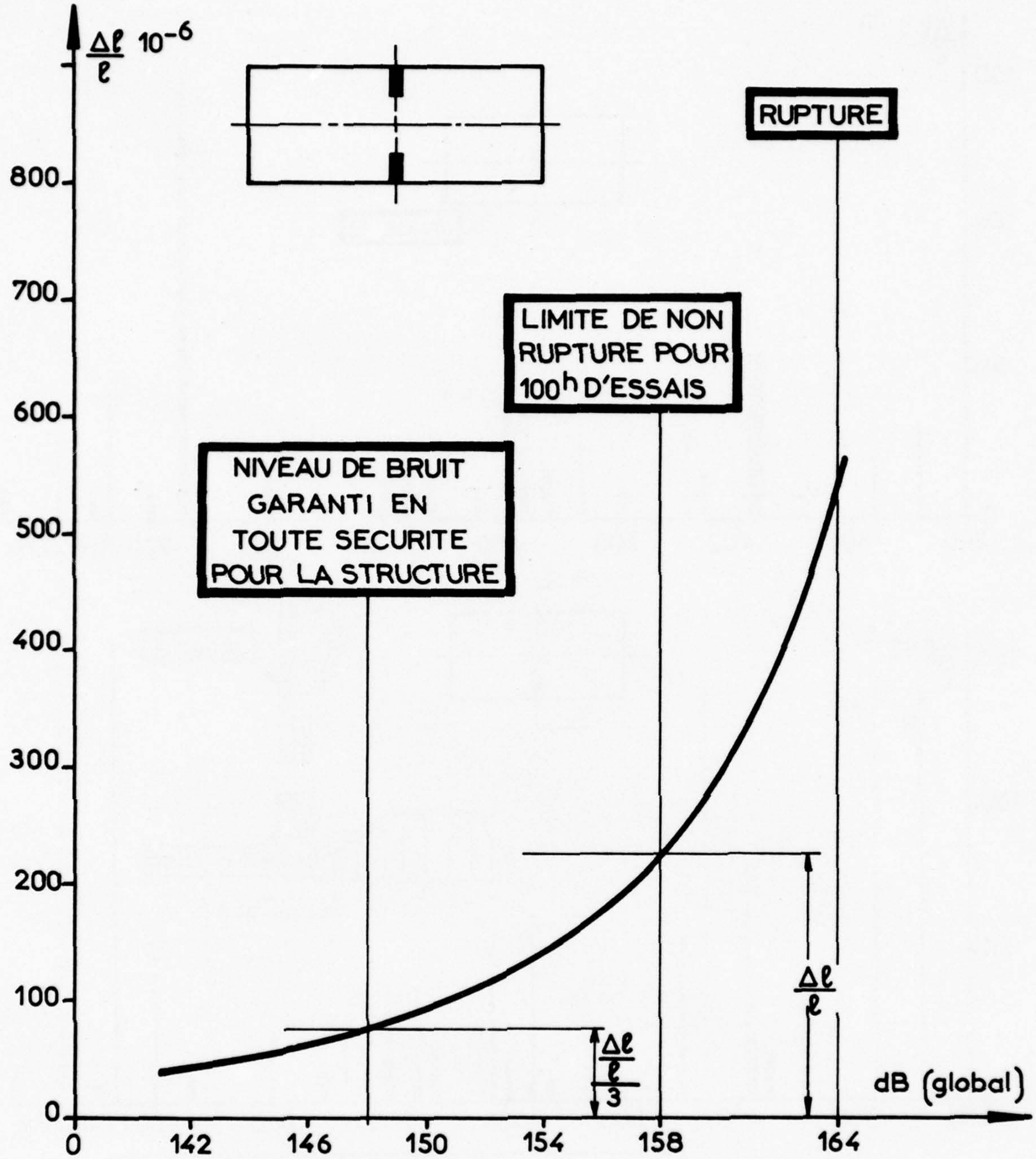


LEGENDE:		
	FIBRE DE CARBONE	FIBRE DE BORE
	NIDA ALLIAGE LEGER	NIDA ACIER

PROBLEME N° 1

COMPARAISON DES SPECTRES DE REPONSE DES 4 TYPES DE CAISSON

Planche 3

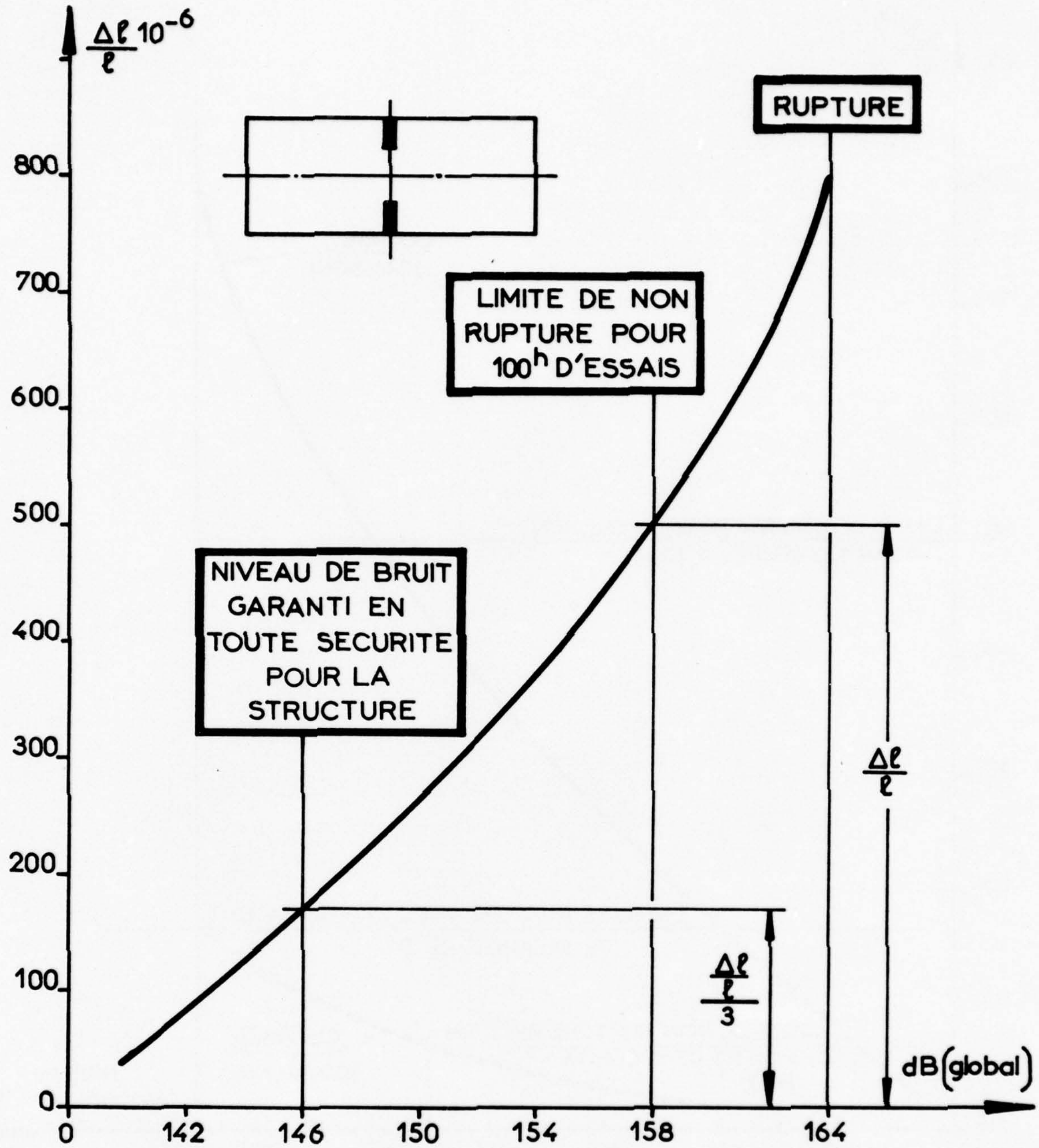


PROBLEME N° 1

CAISSON EN FIBRES DE BORE

EVOLUTION DES ALLONGEMENTS EN FONCTION DU NIVEAU DE BRUIT GLOBAL

Planche 4

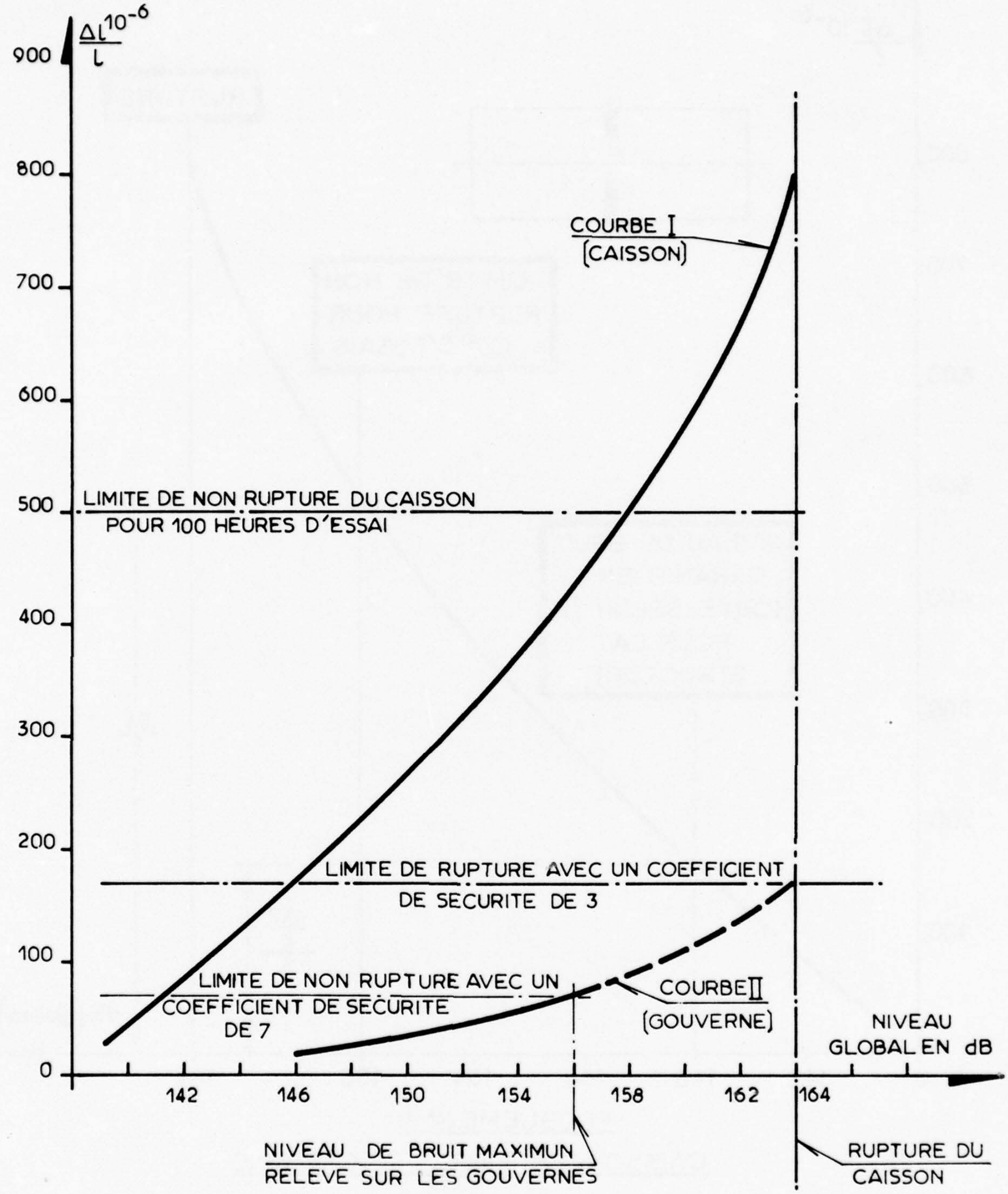


PROBLEME N° 1

CAISSON EN FIBRES DE CARBONE

EVOLUTION DES ALLONGEMENTS EN FONCTION DU NIVEAU DE BRUIT GLOBAL

Planche 5



PROBLEME N°1

ESTIMATION DE LA TENUE A LA FATIGUE ACOUSTIQUE DE LA GOUVERNE

Planche 6

PROBLEME N° 2

VUE SYNOPTIQUE DES ESSAIS

ETUDE DES CARENAGES DE SERVO_COMMANDES

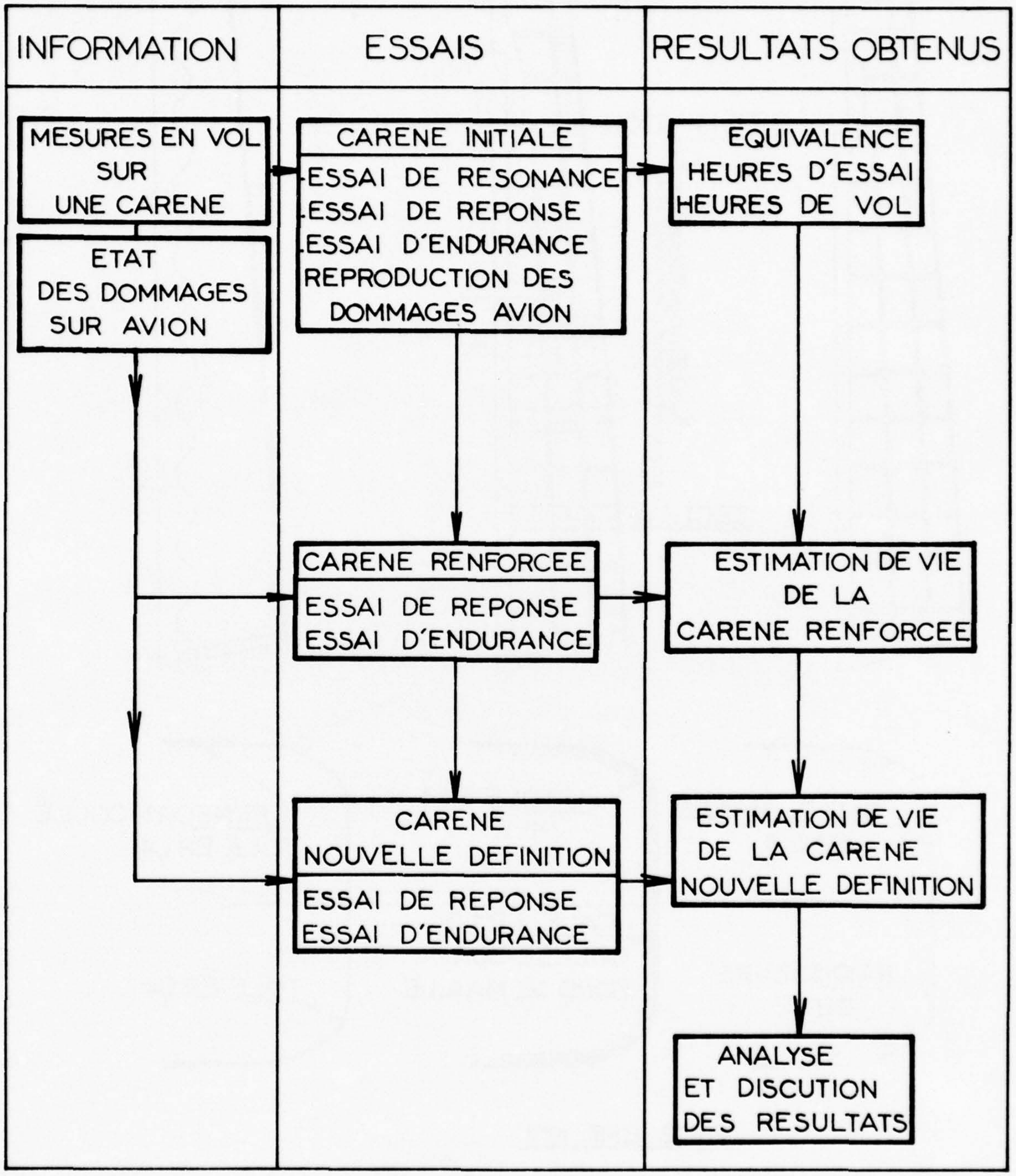
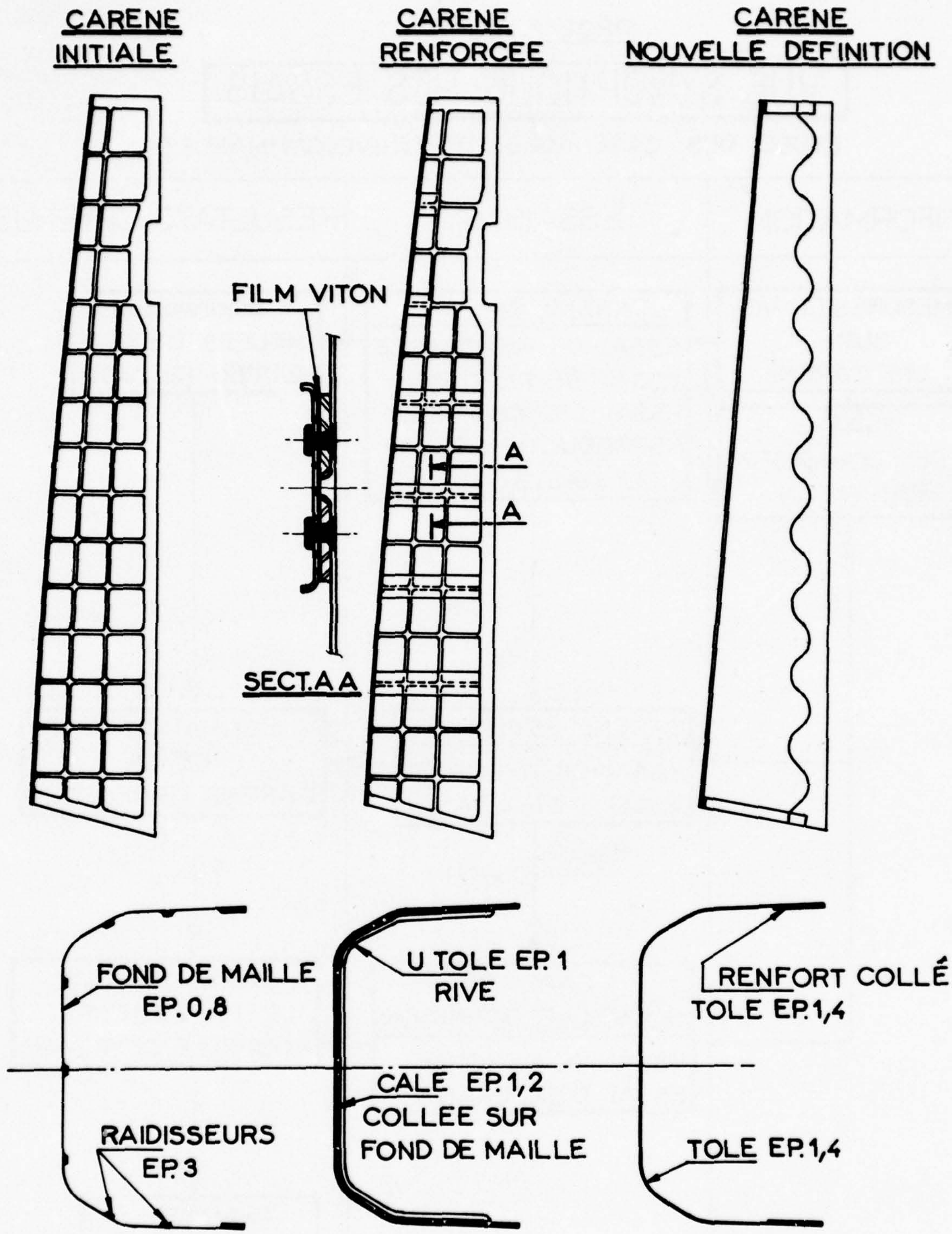


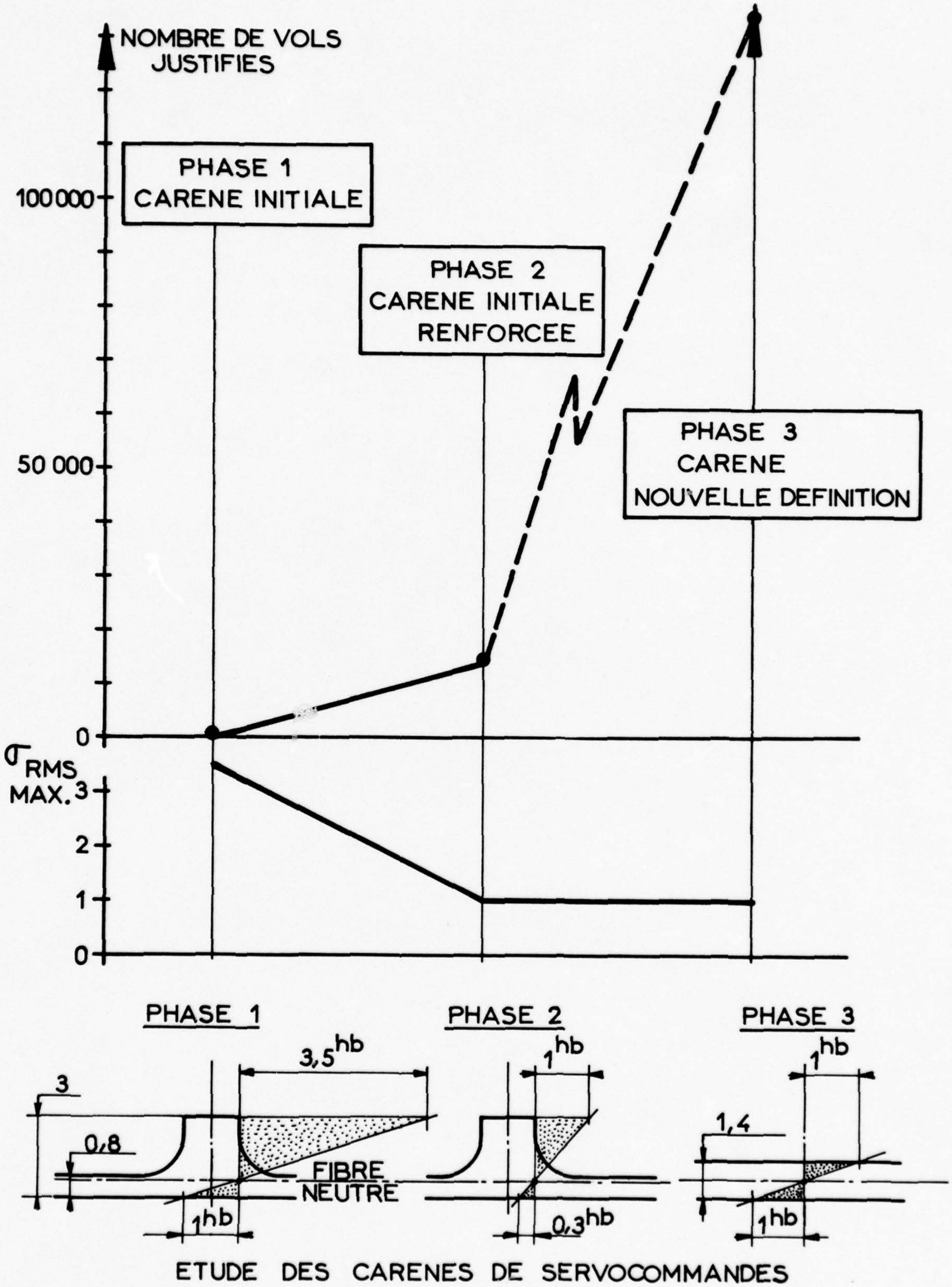
Planche 7



PROBLEME N°2

DEFINITION DES CARENES

Planche 8



ETUDE DES CARENES DE SERVOCOMMANDES

PROBLEME N° 2

ANALYSE DES RESULTATS

Planche 9

REVIEW OF ACOUSTIC FATIGUE ACTIVITIES IN THE UNITED KINGDOM

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SUMMARY

The impact of AGARDograph No.162 (Acoustic Fatigue Design Data) is reviewed with recommendations for improvements and additions to the design aids. Typical airframe acoustic fatigue experience associated with UK project activity is presented. Problems associated with mounting of equipment and systems are considered. An account is given of systematic studies of noise induced crack propagation behaviour in light alloy machined structure and related sub-structure. Examples are presented of R and D activities and findings in the airframe, space and nuclear engineering sectors.

INTRODUCTION

At the last AGARD Symposium on Acoustic Fatigue held in Toulouse in September 1972, U.K. representatives outlined the work that had been or was being undertaken at various centres. Some of this work had been utilised in preparing AGARDograph 162 parts I and II. U.K. papers were presented covering the following topics:

Response and fatigue of light alloy machined plank structures.

The response behaviour of box structures.

Practical experience in relation to damping factors for various structural formats.

Considerations of the fatigue mechanism in light alloy structures subjected to acoustic loads including the effects of static loads and possible crack propagation behaviours.

Consideration of problems related to the response of structures in the aircraft environment as against those realised using siren and other forms of acoustic testing.

Since then these and other contributions supplied by U.K. sources have assisted in the compilation of Data Sheets as released in AGARDograph No. 162 parts III and IV.

A synopsis of U.K. views on the existing AGARDograph is incorporated. In this paper consideration is given primarily to problems that have arisen and information which has yet to be implemented in Data Sheet form but which might be used to provide new guides or to update existing information. In most instances only a resume of the current U.K. information is incorporated, but source references are quoted where possible.

IMPACT OF AGARDograph 162

GENERAL

The collection of Data presents a most welcome compilation of basic information permitting initial design analyses to be made for a wide range of structural configurations. In terms of loading actions the AGARDograph is somewhat limited since it is restricted in quantitative terms to predictions of jet noise and the compass of this is 'conventional' jet noise and buzz saw noise.

It is felt that more information on fan jet noise and buffet excitation in the audio frequency range could be incorporated to give a more comprehensive coverage for application of the existing data sheets. Methods of estimating vibration levels for different classes of structure in relation to the mounting of equipment is another area which has not been explored. Detailed design guidance related to the problems of equipment attachment to structure is also worthy of consideration.

A research of U.K. applications indicates that the use of the AGARDograph is largely confined to specialists in the field. The general concensus is that a more general background explanatory document giving more detailed sample working examples might induce non-specialists to make greater use of the presented information.

LOADING ACTIONS

The near field high velocity jet noise loading action data sheet has had several successful applications and there is general agreement that this data sheet provides a satisfactory prediction technique. It is felt by some though not all of the users that it should be augmented by typical examples of spatial correlation characteristics with riders as to the effects of reflection etc.

The buzz saw noise prediction is also thought to be satisfactory but this is based on certain limited applications conducted to date.

Users feel that methods of assessing the more general near field noise characteristics of fan jet engines could provide a useful addition to this section particularly with the likelihood of improved engines in the foreseeable future.

Again there is a general concensus of opinion that the wider ranging problem of excitation of structures by various forms of flow containing appreciable energy in the audio frequency range requires more detailed consideration. This includes buffet associated with air brakes and other control surfaces, jet impingement and flow over and into cavities. These are currently of importance and are likely to become of increasing importance as structural fatigue loading sources for certain military and civil aircraft. Whilst these phenomena are to an extent a function of the local geometry in question it is generally felt that some basic guidelines on methods of estimating probable intensities and frequency content could be evolved from existing published and unpublished data sources.

NATURAL FREQUENCY ESTIMATION

These data sheet items have been well received and are often used for initial assessments of likely response frequencies for structural configurations.

In the case of box structures it is hoped that further correlations will be forthcoming to confirm the suggested riders relating to governing parameters for choosing the most suitable response frequency in any fatigue calculation.

A number of users have commented on the absence of data related to the influence of frames on natural frequency behaviours.

DYNAMIC STRESS ESTIMATION

Means of assessing stresses in various structural formats are considered to provide useful initial design guidance. The single degree of freedom model which is used is, of course, open to criticism but in providing an initial design guide appears to give an answer of reasonable accuracy bearing in mind the number of potential unknowns which are likely to be involved if a more sophisticated idealisation is attempted (e.g. doubts as to the homogeneity of the excitation pressure and its correlation characteristics, modal damping ratios, structural discontinuities, etc.). However, the user should be fully aware of the limitations of the model and that the presence of multimodal behaviour may have, amongst other aspects, importance as to the possible location of damage initiation in a practical structure.

Specific shortfalls in the data sheet information in the current presentation include an absence of design information on frame and cleat design, reservations about the adequacy of the method of estimating box structure response as currently evolved (the latter can only be improved after more extensive correlations of theoretical and experimental information become available) and an absence of core shear stress estimation in the honeycomb stress prediction data sheet. Frequently core delaminations are a damage source in honeycomb structures and face sheet stresses are not themselves a reliable means of assessing the adequacy of the core attachment.

As more information becomes available users hope that the Data Sheet on damping can be improved.

FATIGUE DATA

The collection of random loading fatigue data for a range of structural elements and materials is considered to form a most valuable part of the AGARDograph. Further information of this kind will be welcomed by all contacted U.K. users including, it is hoped, data on non metallic materials. The other shortcomings which are due to a lack of information available to ESDU appear to include:

Assessment of the differences, if any, between multimodal response fatigue as against the single degree of freedom coupon fatigue data used in the establishment of the quoted fatigue curves.

Effects of a mix of r.m.s. levels with time as might be incurred in practice (e.g. does a Miner's rule hypothesis apply in the case of random loading at acoustic fatigue stress levels).

Assessment of the influence of quasi-static or locked in stresses on acoustic fatigue performance.

Some guidance on likely crack propagation behaviour in light alloy structures and possibly delamination behaviour in honeycomb structures could possibly be evolved from U.K. data.

REVIEW OF STRUCTURAL ACOUSTIC FATIGUE DAMAGE INCURRED ON AIRCRAFT PROJECTS WITH U.K. INVOLVEMENT

The following are typical, though not exhaustive, examples of problems arising associated with commercial and military aircraft projects. They are presented to provide some indication of the nature of damage problems and in certain instances as possible sources for information for use in revising or producing new data sheets.

Whilst a number of the examples are associated with jet noise excitation, there has been increasing evidence particularly with military aircraft of buffet related phenomena generating damage characteristics of typical acoustic fatigue format. In the latter case if the buffet loading action

had been identified at the design stage some, but by no means all, of the damage locations would have been anticipated and the AGARDograph 162 used to realise an acceptable design solution.

The following are reported from ref. 1:

Engine bay doors were manufactured for initial aircraft from conventional light alloy construction with chemically milled inner skins. Originally the minimum skin thickness was 0.4 mm. At that time reservations were made as to the resistance to noise damage based on existing acoustic fatigue data (e.g. AGARDograph 162). An acoustic fatigue test was subsequently carried out which showed damage occurring with slow crack propagation after about one half an aircraft life with negligible reduction in residual strength. For later aircraft the introduction of a minimum thickness of 0.6 mm was found to give a satisfactory solution.

The use of a wing leading edge slat producing high lift at take off and landing and increased high 'g' manoeuvre capability was accompanied by buffet induced fatigue failures. Damage to the tracks was incurred as a result of high vibration loads in the presence of high mean loads due to overall vibration of the slats when they were deployed between $M = 0.5$ to $M = 0.7$ at a maximum EAS of 500 Kts. The vibration was dominated by response at about 80 Hz. Steel reinforcings were added to the track positions. Subsequent tests demonstrated a satisfactory increase in life.

A similar buffet problem was found associated with the deployment of spoilers. Large vibrating loads superimposed on high mean loads gave rise to a hinge failure. Subsequently local reinforcements were introduced and fatigue tests demonstrated a satisfactory fatigue life.

Neither of the foregoing problems would have been aided significantly by information presented in AGARDograph 162.

Associated with the spoiler buffet problem failures were incurred in the shroud panel structure between the wing torsion box and the flap and spoiler system. Various failures of cleats and stiffeners occurred. With a better understanding of the loading action characteristics the AGARDograph 162 could have been of some assistance in improving these design features, including the use of fatigue data, but the shortcomings in relation to design guidance for substructure would have been a major drawback.

A ventral fin was subjected to buffet loads associated with the wake of an airbrake. Substantial reinforcements had to be introduced to overcome this problem. AGARDograph 162 would not have provided a great assistance in this instance.

It was found that a number of tailplane ribs cracked at the flanges on a prototype aircraft due to higher noise levels than originally estimated. In conjunction with BAC Filton a theoretical model was devised which paid special attention to the rib flange deformation. This, in conjunction with AGARDograph 162 fatigue data permitted a choice of revised rib flange which was successfully acoustically tested in a siren specimen. A more recent problem with rib structure required quite extensive modifications which lie outside the bounds of the design guidance in AGARDograph 162. An example of the successful replacement of spot welded titanium structure by a riveted configuration confirms the fatigue data findings presented in AGARDograph 162.

In a few instances noise or buffet induced initial cracking has been observed in aircraft which has then stopped propagating. Fatigue tests on damaged specimens have demonstrated that the total structure retains a satisfactory fatigue life. From ref. 2 it has been established that outboard wing buffet has given rise to cracking of skin panels and substructure. With better loading definition AGARDograph 162 could be used to provide detailed design improvements.

Experiences gleaned from sources refs. 1 and 4 have demonstrated that lightweight heat shields as used in engine bays are highly susceptible to buffet damage. No clear picture has yet emerged on a generally satisfactory approach to improving this type of component, though further flying experience may substantiate the adequacy of the incorporated modifications.

Reported from ref. 2 is buffet excited damage to outboard wing panels. If the buffet loading action had been known greater use could have been made of AGARDograph 162 in the recognition and avoidance of the problem.

In another case failures of skin ribs and stringer were incurred in a control surface necessitating a rapid design modification with an inevitable "overkill" approach. At a project stage investigations were made into jet impingement on a control surface (ref. 3). The loading action was generally identified and it was possible to use AGARDograph 162 to satisfactorily design the skins and substructure. However, it was found that large dynamic hinge moments were incurred necessitating careful reassessment of hinge and associated fitting design.

As far as hinge loads are concerned, similar problems have been experienced elsewhere (ref. 4). In one case doors were excited by jet noise and wear was experienced in the bolt holes of the hinge and actuator mechanism fittings together with actual failure of hinge arms. The problem was identified as excitation of overall modes of the door structure particularly at a frequency of about 80 Hz.

Measurements were made to establish the dynamic loads set up in the door mechanism.

The following are also reported from the same source (ref. 4):

During siren testing of a rudder specimen fatigue damage to a hinge fitting was experienced. A successful redesign was realised.

Buffet and noise in an engine bay resulted in failure of the actuator rod eye end operating a fire flap. Detailed design improvements have overcome this problem.

High intensity noise can produce similar problems in variable geometry intakes, necessitating attention to the design of ramp hinges. Problems experienced with plate like vibrations of large honeycomb ramp surfaces have led to wear at hinge fittings (see fig. 1). The frequency content (circa 140 Hz) was first identified in flight from rear ramp hinge strain measurements. A Nastran analysis established the general nature of this mode and also that it was decoupled from the front ramp from a similar analysis covering both ramps and the operating mechanism (figs. 2 to 4). Resonance tests using an acoustic source identified this mode (fig. 5) and limited spectral and cross spectral analysis confirmed the inflight presence of this mode and the absence of front ramp response at this frequency.

Jet noise induced fatigue damage to prototype fin and wing mounted jack fairings led to theoretical investigations which improved the planned production design. A free vibration analysis using VIPAL (ref. 5) confirmed that portal type vibrations were the cause. A forced vibration model was evolved based on the VIPAL findings. This demonstrated potential improvements to the fairing and support structure, which was subsequently confirmed by siren testing. The main difficulty, which obviated the use of an alternative method of construction, such as honeycomb, was the cross sectional space limitation imposed by potential drag penalties.

During project studies failures of stainless steel honeycomb structure have arisen in combined noise and thermally induced stress environments. The failures have been primarily skin to core delaminations. Siren testing at ambient laboratory temperature conditions has demonstrated the same type of failure but the time scales to failure have been greater than those incurred in the practical example. Theoretical and experimental work is proceeding to obtain design improvements. For certain panels a change to the use of a superplastically formed titanium structure is contemplated.

GENERAL ADDITIONAL COMMENTS

In a few instances where damage has been incurred, where some assessment of the response behaviour can be postulated and where the time to failure can be estimated but the loading action is not defined, it has been possible in work at BAC to assess from AGARDograph 162 the likely fatigue stress in the material in question and in a sense work backwards to establish requisite panel sizes, etc. Indirectly one is providing some assessment of the loading action.

Using a similar approach it may be possible with some of the reported incidents to provide likely guidance on the loading of hinges and supports associated with the response of spoilers, air brakes etc. This may assist in the compilation of buffet damage criteria.

STRUCTURAL DAMAGE RELATED TO EQUIPMENT MOUNTING

Continuing problems are experienced and prediction methods are inadequate in the case of mounting of equipment (including fuel, electrical and hydraulic systems) in structural regions subjected to high noise or buffet. Damage can occur within the equipment, the support fittings or even the main structure.

Reliable vibration level prediction has yet to be obtained. Whilst this is inevitably due in part to lack of information regarding the external noise loading action, probably the more important feature is the need to classify the vibration levels pertinent to different types of structure (e.g. conventional, machined plank, honeycomb, together with the effects of substructure curvature etc.) In the past broad extrapolation from assessments for one aircraft to relate to another (e.g. using the work of Mahaffey and Smith, Ref. 6) without such structural qualification has been demonstrably unsatisfactory. Various prediction methods are available and BAC is in the process of comparing measured vibration levels for different structures with various estimated levels.

Frequently drawing issues for a complex aircraft are too numerous for every fixed fitting or similar mounting used in an equipment installation to be reviewed by a specialist at the initial design stage and this has led to the issue within BAC of general guide lines for equipment mounting techniques in areas of likely high levels of vibration. It is impossible to give a full coverage of the problems encountered in a review of this kind. By way of simple examples problems and design improvements associated with clipping and clamping configurations are illustrated in fig. 6 (ref. 4). Because of the repetitive use of such devices it is important to eliminate such adverse features at the design stage.

Problems have been incurred with equipment items acting as offset masses, which in the absence of sufficient restraint have given rise to damage to the fixed fittings and even the main structure (e.g. equipment attached to frames). Again, general guidelines to enable recognition and avoidance of such problems have been introduced.

Mounting of, say, a fuel pipe on a structural wall can effectively make it an integral segment of the vibrating structure. Here the solution has been to decouple the pipe as much as possible from the vibrating structure. An important point, which may appear obvious, but has arisen in practice, is to ensure that any support brackets are not an integral part of the pipe. Failure of the bracket welded, say, to the pipe not only necessitates complete removal of the pipe for repair but has been known to eliminate any crack stopping capability so that cracking of the pipe itself can occur.

SYSTEMATIC STUDIES INTO NOISE INDUCED CRACK PROPAGATION IN LIGHT ALLOY MACHINED PLANKS AND SUB STRUCTURE

INTRODUCTION

A series of investigations were conducted in conjunction with a civil aircraft project to establish whether the presence of high intensity noise on various areas of the aircraft was likely to have significant effects on the damage propagation rate. In choosing the crack configurations attention was given to both the likely location of acoustic initiated damage together with those directly related to crack criteria for quasi-static loads. Artificial damage generally took the form of saw cuts with a razor 'nick' at the ends to act as a crack starter.

TESTS ON FIN STRUCTURES

This part of the investigation involved three specimens, representing various portions of the fin structure, which had sawcuts and other damage introduced to simulate possible failures. These specimens had all been previously subjected to siren noise fatigue test, although no damage had been incurred during this testing.

The most important noise loading case for the fin is the exposure during take-off, this causing considerably higher dynamic stresses than any other phase of flight. For the calculation of endurance it was assumed that a one hour test exposure was equivalent to forty flights covering both take off, noise in climb, landing and high frequency buffet effects. For the tests on the specimens with damage incorporated at least a two thousand flight interval was covered, that is fifty hours testing. The structural responses measured during the appropriate siren fatigue tests, and also preceding jet noise response tests, were used for setting up the correct siren noise spectra.

On a specimen most representative of the main structure various types of damage were inserted at nine locations in the machined skins and rib attachment members, and also to rib and spar webs.

There was no propagation of the artificially introduced damage at the end of testing.

On a specimen representing the location of the fin jack attachment region where stiffeners were intercostal at the jack rib, three sawcuts were inserted, one each in the skin, rib and spar, at locations likely to be affected by the proximity to the jack mountings.

There was no propagation of the artificially introduced damage at the end of testing.

Six damage locations were introduced into a specimen representing the area containing the main systems. The damage was realised by inserting sawcuts, and in one case by removal of a bolt, in the regions influenced by the attachment of systems components.

There was no propagation of the artificially introduced damage at the end of testing.

BIAXIALLY LOADED MACHINED PANELS

Specially designed panels with the test portion machined to represent typical fuselage dimensions, but also relevant to fin and intake skin panels, were tested in a loading rig. This was capable of applying loads in the plane of the skin in directions parallel and normal to the stringers. The rig permitted siren noise excitation to be applied to the external face of the specimen (see fig. 7).

The following crack geometries were involved to permit an assessment of damage rates and paths (see fig. 7):

(i) cut stringer with nil skin initial cracking and also with 1 inch, 3 inch and 4 inch total artificial skin initial crack lengths equally disposed about and normal to an integral stiffener;

(ii) cut along a stringer radius (3 inch and 6 inch initial lengths were examined);

(iii) cut midway between stringers and parallel to them in the plank central region (3, 6 and 10 inch initial lengths were studied).

The above configurations were tested with predicted aircraft noise induced strains and also included sequential or combined cyclic quasi-static loads, viz;

A sequence of take off noise conditions followed by pressure cabin or rear fuselage static loading (the static load dwell period was usually much shorter than incurred in aircraft practice, but the take-off noise exposure was typical). In addition some sustained rear pressure cabin load cycles were included. In these instances they were accompanied by noise representing boundary layer excitation.

The crack propagation characteristics were generally summarised as:

Configuration (i) cracks : these propagated rapidly from a small crack length but had reduced to negligible crack growth at four inches.

Configuration (ii) crack rates were rather slower than configuration (i) and the rate was negligible at six inches.

Configuration (iii) cracks had in general the slowest propagation rate of all.

The general feature (particularly configuration (i)) was that cracks tended to develop different directional crack fronts (up to three per artificial edge).

The details of cut lengths, test loads, test cycle exposures and propagation damage are given in table 1.

PRESSURISED FUSELAGE SHELL (fig. 8)

Tests were carried out on a fuselage shell which had originally been used for quasi-static loading fail safe investigations. This development specimen was used in order to introduce the correct distribution of stresses due to pressurisation and the dynamic response of curved structures. A new plank and local support structure was introduced into the shell for the acoustic studies. This test panel was machined from CM003 material and covered four frame bays and included 9 machined stiffeners. Representative frame sections were used over this panel area. A test siren was positioned so that the damage location under test could also be subjected to a representative noise loading. In the main series of tests three types of damage were sequentially incorporated.

(i) A six inch skin cut midway between integral stiffeners and through a frame. The frame was severed except for the 'fail-safe' angle. (fig. 9)

(ii) A six inch skin cut midway between frames and positioned parallel to, and midway between, two adjacent stiffeners. (fig. 10)

(iii) Two similar damage configurations consisting of a cut in a stiffener with no initial penetration into the skin and secondly a cut stringer with a one inch total symmetric cut in the skin. Both locations were midway between frames. (fig. 11)

In all cases the following loading sequence was applied:

Noise loading producing strains assessed to represent take-off noise levels in the rear pressure cabin falling during the pressure cycle to levels considered representative of response to boundary layer noise excitation. The pressure cycle, which occupied a period of approximately five minutes duration, reached a total sustained pressure equivalent to that associated with normal pressurisation plus a factor to allow for thermal and other effects.

A thousand cycles was realised on configuration (i) with a total propagation of about two inches. This was followed by a successful residual strength test.

The specimen was repaired and configuration (ii) introduced. After this crack had propagated to a total length of twelve inches a further five hundred cycles were applied. After the first fifty three cycles the crack had reached the frames. Allowing for inevitable scatter the number of cycles involved could be said to be similar to that expected from static pressure cycling alone.

At the end of the five hundred cycles the crack had not propagated beyond the frames.

After repair a one thousand cycle test was achieved on cracks of configuration (iii) without incurring any propagation.

Subsequently certain other tests were performed.

The configuration (iii) damage was incorporated but with a more extensive initial crack size after achieving five hundred cycles. One cut was sawn to a total length of four inches, symmetrical either side of the stringer, and the other cut was sawn into the radius of the adjacent stringer on each side, giving a total length of about 8.3 inches.

In addition to the loading programme already described a noise level equivalent to the boundary layer excitation was applied while the specimen sustained an internal pressure of 12.85 psi. This was to represent a real time aircraft cruise situation and the loading held for two hours.

After five hundred load cycles had been completed, plus the two hour run simulating the real time cruise condition, there were no visible signs that the cuts had propagated. Dye penetrant tests showed five small "star" cracks at the ends of the four inch cut, and a small crack at each end of the longer cut, the maximum crack length detected being about 0.22 inches.

GENERAL REMARKS

The main conclusions that can be drawn from this test programme for the noise levels in question are that cracks often propagate rapidly initially from small crack lengths, but the rate is soon retarded which may be associated with the bifurcation which often occurs. Cracks do not appear to propagate from large initial cracks (i.e. those introduced to represent cracks arising from factors other than noise).

It should, however, be recalled that at higher noise levels than were found in the pressure cabin in question crack propagation can be both rapid and extensive (see ref. 7). Work is planned to correlate these findings and those of ref. 8 using fracture mechanics aids in order to try and realise a better understanding of the propagation mechanism.

RESEARCH WORK IN THE UNITED KINGDOM

GENERAL

This review does not attempt to give an exhaustive description of the work that has been conducted but endeavours to highlight some of the more important facets of research activities.

AIRFRAME ORIENTATED STUDIES

LOADING ACTIONS

This work has been confined to assessments of the nearfield noise characteristics of jet engines. Measurements made with an Olympus 320 engine have been fully reported in Ref. 10. Advance data from this source was used in assessing the efficacy of the AGARDograph 162 jet noise prediction method. Information on space-time correlation characteristics is also included in this reference.

The nearfield characteristics of another military aircraft powerplant have been explored as part of the investigations described in ref. 11. As yet the full loading action data has not been published. This information could be used to provide further checks of the existing data sheets and some information on spatial correlation characteristics is also available.

Nearfield noise measurements have been made in the presence of an RB211 fan jet engine. These are described in Ref. 12 and include spectra and correlation characteristics.

BAC STRUCTURAL RESPONSE AND FATIGUE INVESTIGATIONS (Ref. 11)

In order to provide more detailed design guidance in relation to machined plank structures for enhanced data sheet presentation work continues on an extensive programme under a UK Government contract. Six progress reports and a number of appendages have been issued to date. Only typical examples of the findings can be given in this review. A final detailed appraisal report should be published around the end of 1977.

The work has consisted of both experimental and theoretical investigations into the dynamic behaviour of such structures together with fatigue testing of panels and coupon specimens.

The specimens used for the experimental studies were designed primarily on fuselage structural stability criteria and having at least three frame bays. The frames are of typical aircraft construction and were common within cross sectional dimensions for each specimen. Details of the machined plank variants are given in fig. 12.

In order to establish theoretically the modal properties various techniques were used in the earlier stages (1972) including a finite element programme developed at Filton, and a Transfer Matrix analysis. These were generally restricted to considerations of a single frame bay. In addition simple analytical models were used particularly to deal with the frame/plank response where the plank was treated as an orthotropic plate.

More recently use has been made of VIPAL, VIPASA (ref. 5) and NASTRAN to examine single and multi frame bay effects.

Initial stress prediction methods were based on single degree of freedom response models (flat and curved plate) (figs, 13, 14) similar to the one subsequently developed for use in the AGARDograph 162. Comparisons are currently being evaluated using the latter method. The wave group approach (e.g. ref. 13) is also being applied which has been used in the study of box structure response by BAC and has also been used by HSA as mentioned in the following section. There are serious doubts as to the applicability of the statistical energy analysis (SEA) because of the relatively low modal density in the important 100 - 1Khz range although with the plate-like behaviours of the stiffened planks this has yet to be completely ruled out for all the structural configurations. Sample forced response finite element model studies are in hand together with certain simpler analytical models.

Experimental identification of modes was primarily contained to verification of the theoretical analysis and in establishing the nature of the predominant modes observed in jet noise response studies. Various approaches have been made in conducting resonance tests. Initial work used acoustic excitation with the siren supply signal acting as a common reference. Difficulties were experienced in realising satisfactory modal resolution using the usual polar plotting with displaced origin assessment techniques, due to complicated phase relationships arising in some instances. Whilst this was thought to be attributable to local variations in joint stiffness and dampings, etc., it was also suggested that this simple representation of the generalised force of the spatially distributed excitation forces was inadequate.

In an attempt to overcome this possibility a number of tests were conducted using an electromagnetic exciter as a nominal point excitation source. Some small improvement in the phase relationships was observed but depending on the nature of the mode and the location of the exciter modal distortion has occurred. This is attributed to the presence of the exciter and has been supported by theoretical studies examining the exciter effects.

Time averaged holography has also been used with excellent results for the limited examples studied. The specimen was excited at resonance by a loud speaker. The vibrating structure was illuminated by a gas laser and a photograph taken with an exposure time encompassing several periods of oscillation. The sinusoidal nature of the vibration together with the coherence of the laser causes the displacement of the panel to be recorded as fringes, which provide an excellent indication

of the panel displacement pattern, see fig. 15. The experimental set up is shown in figure 16.

The initial setting up of the specimen is tedious with any extraneous vibrations presenting a problem. Covering the whole panel area the facilities available was time consuming as only a segment of the specimen could be photographed at a time. Nevertheless the limited experiment was encouraging and demonstrated the potential of this technique. The established mode compared favourably with other experimental findings and in some respects provided more detail of the mode.

The acoustic excitation technique using Vector plotting analysis proved overall to be the easiest method and usually gave results of acceptable engineering accuracy. The usual difficulties were experienced with all methods when the modes were closely spaced.

Further research using scaled up versions of proximity exciters as for example used in aeroelastic wind tunnel model resonance tests might provide a more satisfactory means of specimen excitation for assessing modal properties.

In addition to the resonance tests, extensive jet noise response tests have been conducted with the panels located at several positions in the near field and detailed measurements of the relevant loading condition realised with flush mounted microphones in 'dummy' specimens.

A number of siren response tests of the panels has been undertaken for various reasons including the setting up of fatigue investigations. As was expected, because of the differences in the correlation characteristics of the two excitation fields, considerable siren spectrum shaping had to be employed to realise the response of the more important modes observed in the jet noise investigations.

During these studies an interesting and as yet unexplained feature emerged. With one specimen the structure including its surround was freely mounted with bunjee rather than using the usual solid mounting configuration. The modal content for both configurations was normally the same except at very low frequencies where overall modes were affected. However, the general level of response with the specimen solidly mounted was found to be substantially greater than in the freely mounted case.

It was found theoretically that the presence of the frames, in a multibay model rather than the assumption of nodal boundaries in a single bay model, tended to result in a greater spacing in frequency of the modes. This tends to be borne out by the experimental findings.

Strong coupling between the frames and skins with frames not necessarily acting as nodes was established both theoretically and experimentally for most panels. Studies of panel 5, as yet incomplete, may indicate that with a reduced generalised stiffness and mass of the plank compared to the frame a single frame bay representation could be possible in certain circumstances. Sample examples of modal behaviour are given in figs. 17 to 19 inclusive.

Panel siren fatigue testing has so far been restricted to panel 1. Failures of the frame heel and damage to frame stringer cleats has been realised.

Random loading single degree of freedom coupon fatigue data using both free-free beams and 'butterfly' tee specimens all in L 93 material (corresponding to the machined plank specimens) have recently been completed. The results appear to show rather better fatigue values than demonstrated by the AGARDograph 162 for other light alloy materials. However, further checks have to be made for the dynamic stress distribution as cracks did not always occur exactly at the monitor strain gauge positions. It is not envisaged that major changes will be seen in the data given in figs. 20, 21.

HSA STRUCTURAL RESPONSE INVESTIGATIONS

GENERAL

This work has been fully reported in refs. 14, 15, and only general typical findings are included here.

RESPONSE ASSESSMENTS

Extensive theoretical and experimental treatment has been concentrated on one panel configuration of conventional light alloy construction format (see fig. 22).

Both jet noise, grazing incidence siren, normal incidence loud speaker, and mechanical excitation tests have been adopted. Similar problems to those discussed in the BAC R and D review were experienced during the course of these investigations including problems associated with siren equivalence in simulating jet noise response characteristics. Additionally it was found that the edge support conditions for the panel had a significant influence on the response behaviour.

Tests were also conducted with an enclosure placed behind the specimen during the jet noise tests. The effect was to generally reduce the response levels, due primarily to the lowering of the noise levels on the surface facing into the box. It has not been possible to establish with any certainty the influence if any of the cavity acoustic modes on the response behaviour as there were also some variations incurred in the panel peripheral restraint.

Sand patterns successfully established under discrete frequency excitation have also been used to identify skin model characteristics (BAC have also used this technique in the past with flat conventional, but not machined structures).

In terms of theoretical modal analysis both finite element, transfer matrix, wave group theory and VIPAL have been used.

In terms of stress prediction certain single degree of freedom models were assessed due to Clarkson (AGARDograph 162 basis) Ballentine and Arcas. It was felt that the AGARDograph 162 was as accurate as any of the single degree of freedom models, the latter assumption being more likely to provide deviations from the true values than the modifying assumptions contained in the different versions.

Stress estimations were also obtained from wave group theory and normal multimode analysis.

Stress lacquer techniques were applied and demonstrated high stress concentrations around frame cutouts at stringers.

Sample examples of the modal behaviour and comparisons of predicted and measured stresses are given in figs. 23 to 26.

RAE RESEARCH STUDIES (ref. 16)

An experimental programme is being conducted into the effects on fatigue performance of random loading containing a sequential mix of r.m.s. stress levels on coupon specimens compared with the fatigue data realised from tests on such specimens at particular sustained r.m.s. levels. A Miner's law criterion appears to correlate well with initial findings.

In addition, comparisons are being made between the stress distributions at joints under static bending loading and those when dynamic excitation is applied.

CARBON FIBRE REINFORCED PLASTICS (CFRP) STRUCTURES

The Institute of Sound and Vibration Research, Southampton University, conducted a number of investigations related to the dynamic response and acoustic fatigue behaviour of CFRP. These have included:

Theoretical free vibration models of CFRP beams and plates including examining the effects of delamination.

Experimental studies of the dynamic behaviour of beams and clamped plates.

Experimental studies of the effects of fibre orientation or delamination behaviour.

Both acoustic fatigue testing and non destructive inspection for delamination (ultra sonic scanning) facilities have been developed.

The main findings to date indicate that for configurations likely to be used in practice (e.g. 60% fibre volume fraction):

(1) The internal damping is very low in a typical frequency range 70 to 700 Hz (Damping Ratio, δ , = 0.002 to 0.004). This finding is confirmed by work carried out at Bristol University by R. Adams. The damping ratio can be increased by the application of random fibre orientation of the surface fibres. As a result some increase in weight is incurred but there is also a stiffness increment so that in practice the weight penalty should not be severe.

(2) CFRP structure can exhibit a marked non linearity at high noise levels. For example there is quite good correlation between theoretical modal prediction and experimental behaviour of clamped plates with around 130 dB broadband noise excitation with a clear indication of various plate modes. For similar levels of vibration the modal characteristics of simple structures with delaminations can be predicted with reasonable accuracy. However, with 150 dB broadband noise excitation there is a much greater 'blend' into a broadband response spectrum which is clearly associated with non-linear dynamic characteristics.

Future work at the ISVR is likely to extend to acoustic fatigue assessments of simple and built up structures with more detailed analyses of the non linear behaviour together with methods of stress prediction particularly involving correlation with delaminations in plates.

Detailed examples of the described ISVR work are given in ref. 17.

In industry little work in the acoustic fatigue field has been undertaken to date, though a limited number of flight and laboratory studies are planned which will be correlated with design analyses.

SPACE RESEARCH AND APPLICATIONS

GENERAL

Increased emphasis has been placed on the need to design for the effects of noise at lift off and pressure fluctuation phenomena associated with flow excitation during the pre or post orbital phase.

Concern is related to ensuring the integrity of pay load structures (e.g. antennae, solar arrays, thermal panels) and determining vibration levels and coping with their effects in relation to structure

mounted equipment items (e.g modules and pallets with their equipment).

Similar types of problems as experienced in the airframe field are currently being assessed including accurate definition of the structural acoustic loading actions, establishing a balance between theoretical and experimental studies to achieve satisfactory designs, and realising methods for realistic simulation tests in laboratory conditions.

U.K. ACTIVITY

In the United Kingdom project work has been conducted by Hawker Siddeley Dynamics and has been associated with the Spacelab pallet and the Ariane launch site flue. They have also undertaken research work for the European Space Agency (ref. 18) in relation to normal mode finite element analysis to cover lower frequency aspects and the use of statistical energy analyses (SEA) to extend the frequency range. Computer programmes have been evolved in conjunction with this work.

Because of the nature of the structural elements and sizes in question the higher frequency range can pose structural acoustics problems and in this context with high modal densities the SEA approach can offer design guidance. (In the airframe field SEA has generally been restricted to sound transmission analyses which lie outside the scope of this review.)

In initial research the two above approaches were applied to simple plate and cylinder models with reasonable correlation with laboratory measurements.

As in the case of airframe experience, providing the acoustic loading action is known the main problem using the normal mode approach lies in the scope of the finite element modelling technique and reliable predictions of modal damping behaviour.

HSD have extended the SEA evaluation to consider more complex structural configurations. These have consisted of thin walled right cylinders 0.7 and 0.4 m in diameter and 0.7 m in length. Both lateral and external plate floors have been examined together with an internal transverse floor. In the latter instance a single integral hoop stiffening was also incorporated. The cylinder ends were closed by chipboard. All stiffeners or floors were either attached by continuous welds or closely pitched spotwelds. This form of attachment was used in order to try and produce uniform structural damping and to permit strong coupling between the substructures. The latter was pertinent to the demonstration of aspects of the theoretical concepts. Each cylinder had three equi-spaced longitudinal stiffeners.

Correlations have been made between theoretical and experimental findings for reverberant excitation conditions. The theory and results are too complex for a complete detailed discussion but a general synopsis is given below:

If strong coupling occurs then the analysis is simplified since an equipartition of modal energy can be assumed. This means that for two strongly coupled interacting systems the energy of each mode of each system is equal to the energy of every other mode. The energy content of each structural component is then dependant on its modal density.

Under the conditions for which SEA is applicable the presence of stiffeners can be demonstrated to lead to a higher coupling between the sound field and the structure, thereby leading to an enhanced response. This is associated with modal distortions at substructure boundaries. This phenomenon has also been observed in the USA, confirmed by the HSD experimental investigations and further substantiated during experimental transmission loss studies conducted by BAC on stiffened and unstiffened panels.

The theoretical concept that the modal density of a simple hoop frame or axial stiffener decreases with increasing frequency was confirmed during the experiments.

The response of the floors has been attributed to strong coupling with the cylinder skin and was not influenced significantly by the effects of the enclosure cavities. The response of the external peripheral floor was particularly high which is attributable to the high modal density associated with this component.

For cylinders, generally good agreement is indicated between SEA and experimental findings for frequencies greater than about half the ring frequency. The range is extended in the presence of axial stiffening due to the enhancement of the radiation resistance of acoustically slow modes. At lower frequencies the low modal density tends to invalidate the SEA approach.

The best theoretical correlation with experimental data was obtained using a damping factor of 0.5%.

A method of assessing possible maximum rather than space averaged response behaviour at regions well removed from structural interfaces has been evolved. It does not, however, lend itself to assessments at structural boundaries due to local distortion effects not accounted for in the assumed mode models. This could possibly present problems when considering structural damage at interfaces. The method also becomes less accurate in frequency regimes having a very high modal density, probably because such modes are assumed to have a maximum response at a common point in the structure, though this could well occur at some point on the structure.

Through lack of time for review the information available to the writer is incomplete and it is not known whether the basic good design practice guidance techniques commonly used in airframe acoustic fatigue problems is utilised in the UK space sector. There is also some doubt as to whether the modifying features due, for example, to the introduction of nominally discrete mounting of equipment or systems on the main structure has received attention using the SEA approach. Nevertheless, the work

has demonstrated that general space averaged levels of vibration likely to be experienced can be predicted together with possible extreme values, at least for near reverberant excitation sources.

The particular problems associated with hydrodynamic excitation do not appear to have been studied using the SEA approach, though work of this type has been conducted outside the UK, particularly in America for space structures. In the UK this has been considered in relation to boundary layer induced aircraft internal noise problems.

BAC were engaged at an early project stage of the Space Shuttle in considering acoustic fatigue problems of titanium structure planned at that time for application in the construction of cargo bay doors. Initial design guides were produced for the structural format in question.

ACOUSTIC FATIGUE IN THE NUCLEAR REACTOR FIELD

Acoustic fatigue problems have arisen in UK nuclear power reactors. Of particular concern is the effect on structural components of high coolant gas mass flows arising in the extensive gas circulators. It is estimated that 0.1% of the installed horsepower is available as acoustic energy giving rise to high sound pressure levels.

This has led to research into methods of predicting the noise distribution round the gas circuit using both theoretical and experimental models and methods of predicting the associated structural response.

In the main the basis for stress prediction is based on what may be loosely described as a statistical energy analysis approach which is an effective tool as high modal densities are usually involved. Allowances are included in the prediction method to assess the effects of structural discontinuities. Stress predictions with an accuracy of two to three are realisable and tend to be pessimistic.

Further investigations have been conducted to study the effects of varying reactor operating conditions and to provide methods of establishing the likely changes in r.m.s. stress levels. The work has been extended to include the effects of different gas coolants, viz. helium, carbon dioxide and air.

Once a nuclear reactor has been built extensive vibration monitoring is included in the commissioning phase to assess the accuracy of the predictions.

Examples of the work are given in ref. 19.

CONCLUDING REMARKS

AGARDograph 162 provides a useful initial design guide though it is generally felt that design instructions are required before it can be extensively used by non specialists.

Both practical experience and research studies have indicated that further information preferably in data sheet form would be welcomed on :

- buffet excitation phenomena;
- the design of sub-structures including frames and ribs;
- the mounting of equipment on vibrating structures;
- extension of the fatigue data to cover such features as:
  - the importance of overall mode and multimode effects;
  - mixes of r.m.s. levels as may be incurred for example through jet noise excitation on the ground and varying degrees of buffet intensity in flight where nominally similar 'audio frequency' modes are excited; compilation of random loading fatigue data for other materials and configurations such as steel, reinforced carbon fibre plastics, honeycomb, etc.

Information that could be supplied from such sources as refs. 1 to 4 would assist in such data sheet compilation.

The difficulties associated with theoretical stress prediction and laboratory simulation of practical response behaviours, including modal identification, have been highlighted by practical and research experience. These are believed to warrant further study.

UK experience indicates that there appears to be scope for a greater exchange of information between airframe, space and non aerospace sources which could be of mutual benefit in producing wider ranging design aids.

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I am grateful to my colleagues R. Cummins and J. Cooper for assistance in researching our own archives the material included here. I would like to convey my appreciation to, amongst others, A. Peacock (BAC), N. Townsend and E. Phillips (HSA), R. White (ISVR), P. Whitton (CEGB) and W. Kirkby (RAE) for useful information and discussions related to subjects contained in this review.

TABLE 1

BIAXIAL PANELS

SUMMARY OF TESTS

PANEL No.	TEST STAGE	POSITION OF CUT		LENGTH OF CUT	O.A.S.P.L. dB	STATIC STRAIN micro strain		TOTAL 'FLIGHT' CYCLES	TOTAL PROPA-GATION
		AXIAL (PARALLEL TO STRINGERS)	HOOP (ACROSS STRINGERS)			AXIAL	HOOP		
1	1		'Thro Stringer 4 on centre line.	1"	158·5	400	- 20	370	·78"
1	1		"	3"	"	"	"	400	·27"
1	1		"	4"	"	"	"	632	·10"
1	2	Root of Stringer 2		3"	158·0	290	175	200	0
1	2	"		6"	"	"	"	820	·88"
2	3	Mid-Bay Stringers 2/3		3"	"	290	175	860	·54"
2	3	"		6"	"	"	"	600	·21"
2	4	"		6"	139·5	-320	440	1000	·13"
2	4	"		10"	"	"	"	1003	·40"
5	5		Thro' Stringer 2 on Centre Line	Web Only	157·5	400	20	807	·95"
5	5		"	3"	"	"	"	200	0
5	6	Mid-Bay Stringers 3/4		3"	156·5	300	180	181	0
5	6	"		6"	"	"	"	510	0
5	6	"		6"	158·0	No Pressure Cycling		420	·20"
5	6	"		10"	"	300	180	390	0

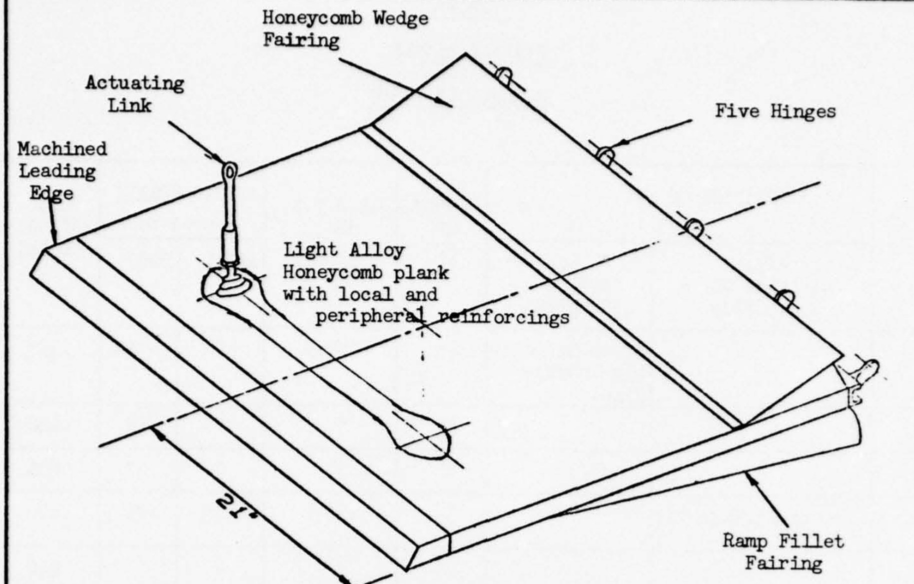


Fig.1. Details of Rear Ramp Layout

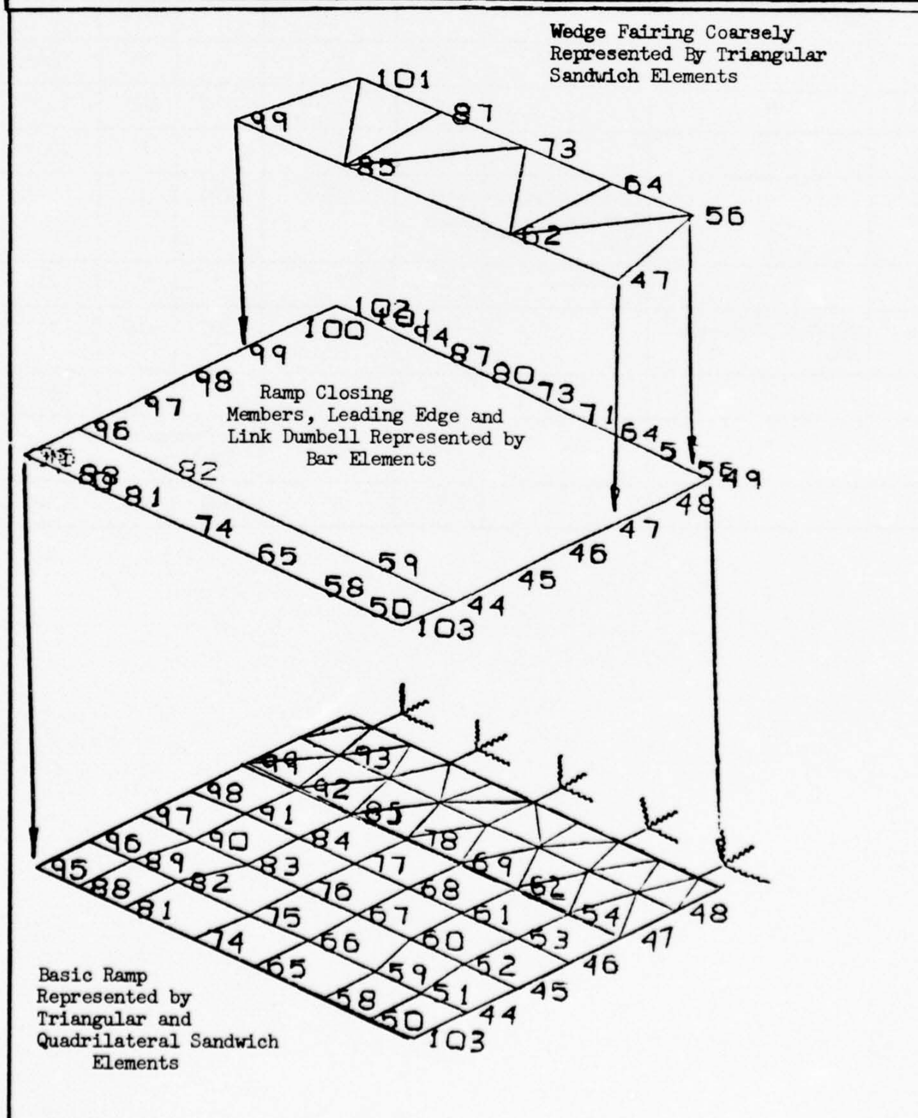


Fig.2. Rear Ramp Theoretical Model

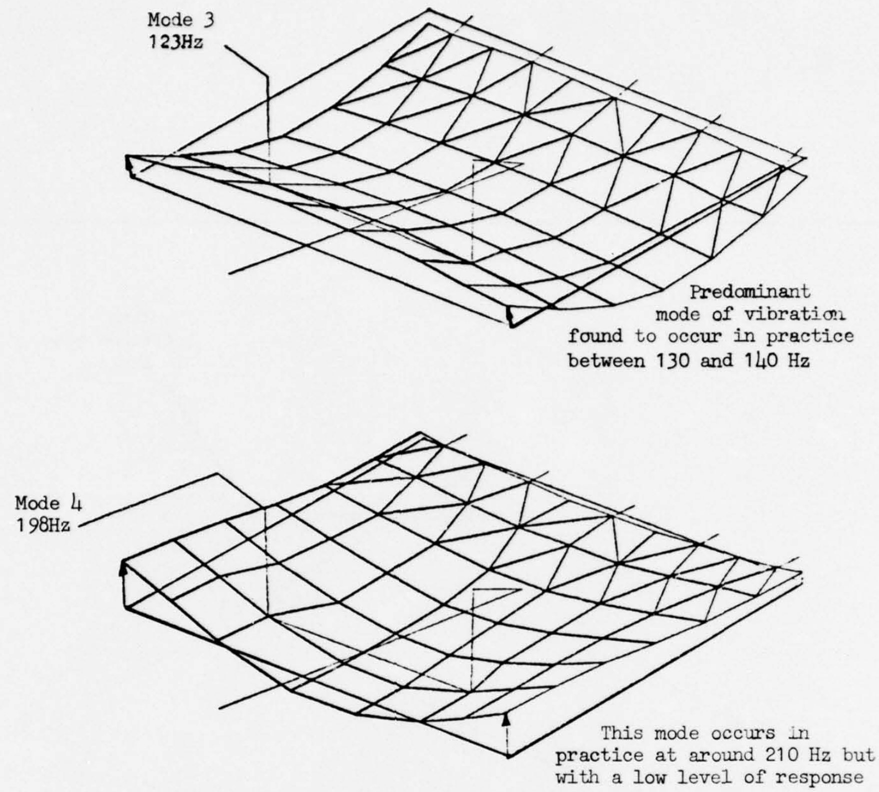


Figure 3 : Nastran Analysis of Intake Rear Ramp Modes of Vibration

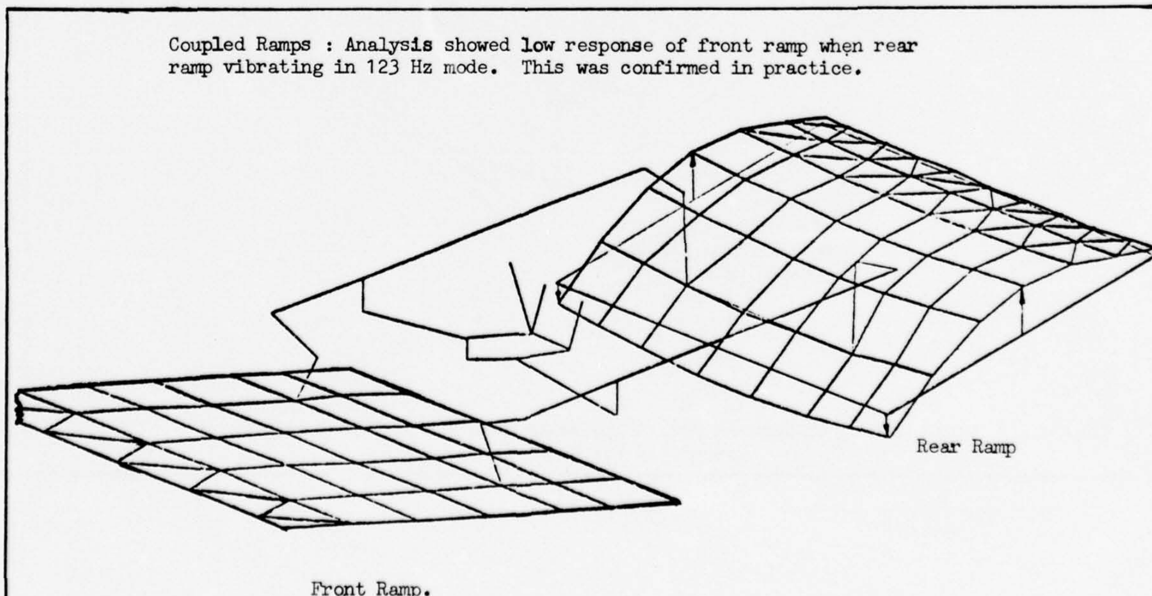


Figure 4 : Analysis of Coupled Rear Ramp, Front Ramp and Actuating Mechanism.

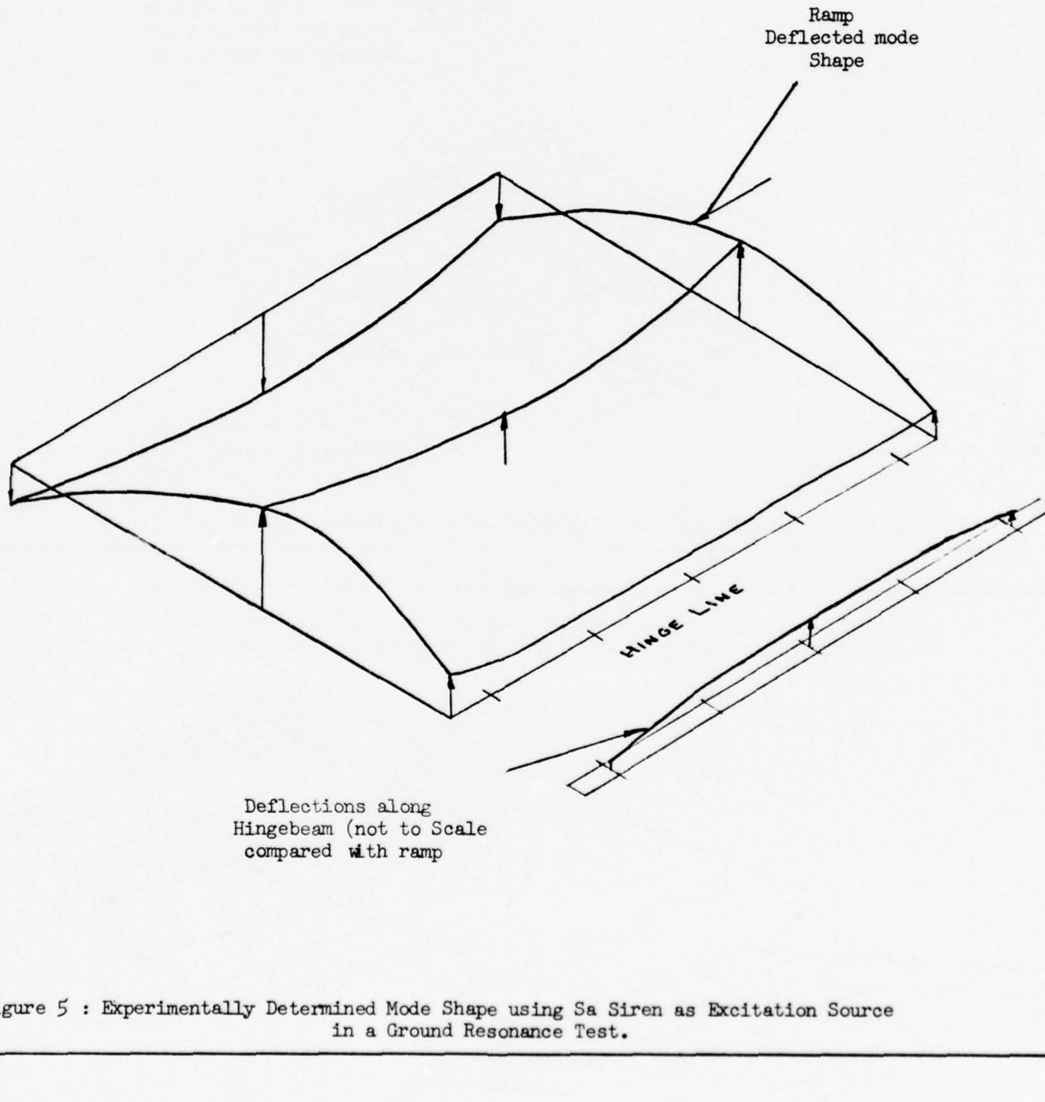
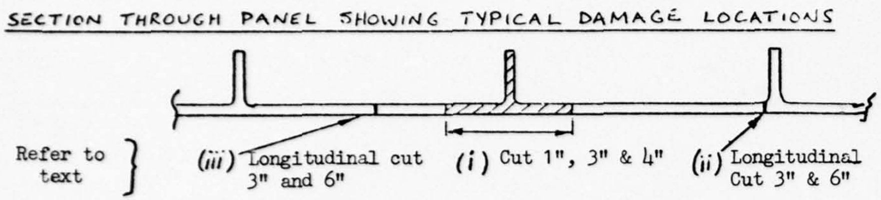


Figure 5 : Experimentally Determined Mode Shape using Sa Siren as Excitation Source in a Ground Resonance Test.



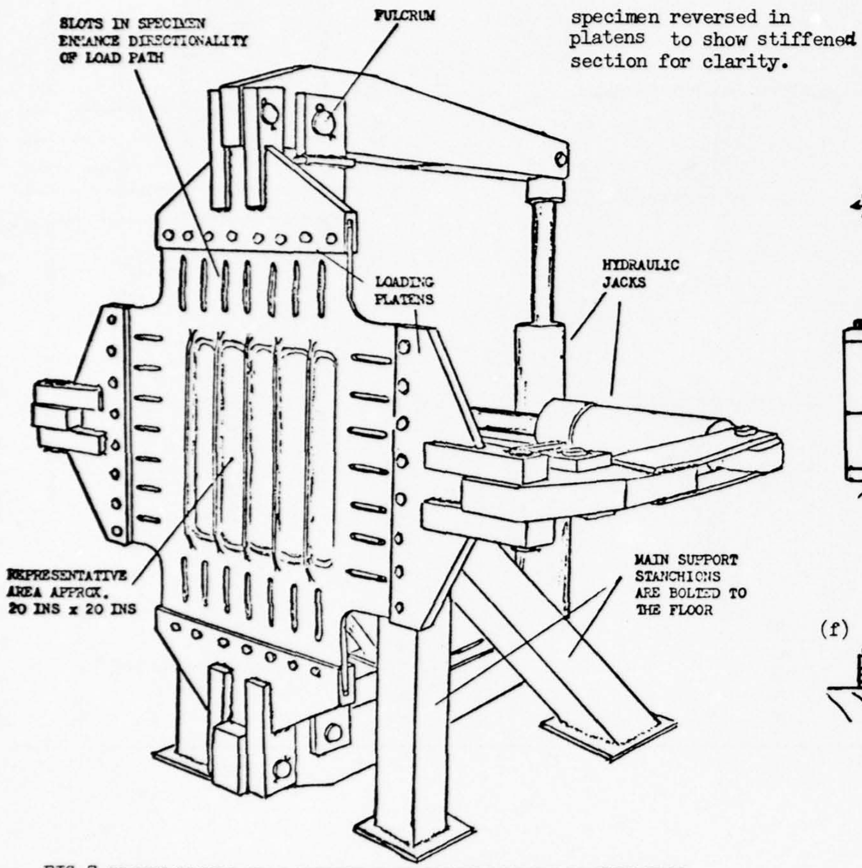
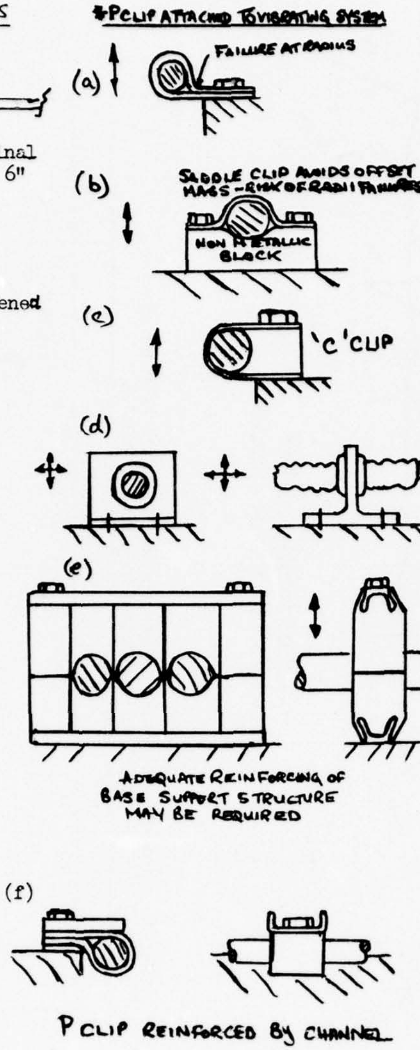


FIG 7 BIAXIAL LOADING RIG & MACHINED PLANK SPECIMEN FOR USE IN SIREN TESTS.



In regions where vibration is possible P clips should be avoided.* If a P clip is unavoidable it should be used in accordance with the type of improvement suggested in (f) below.

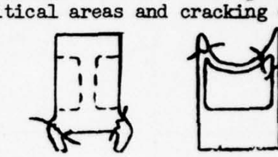
The choice of saddle material should be resolved with Stress Office, the choice of the block material depends on the local environment but also a material with directional properties should be avoided

Avoids sharp radii and has enhanced rigidity which provides greater resistance to offset mass effects.

Simple extrusion with a grommet may suffice where no positive fore and aft rentation is essential the example shows cable carrying superflexit in situ.

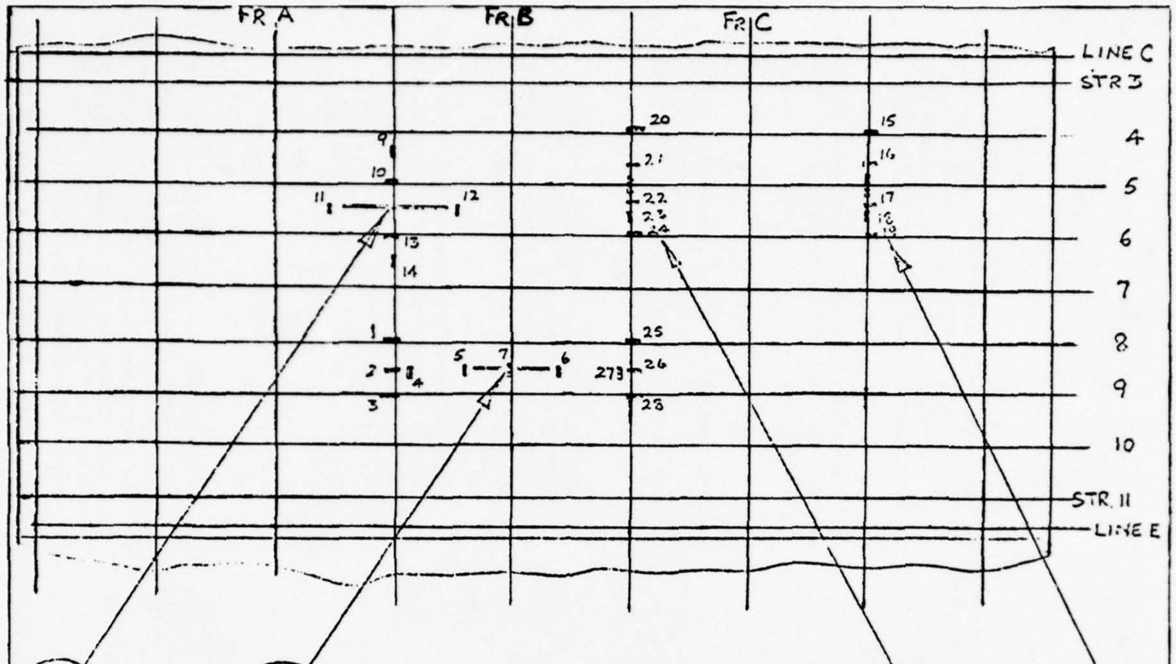
Clamp Block (e.g. 'air lb' type as drawn) Choice of block material without directional properties is essential otherwise cracking and eventual break-up will ensue, e.g.

if directional fibre composite is used fibres tend not to follow contours leaving mainly resin at critical areas and cracking ensues as shown:



Sometimes the use of a P clip is unavoidable due to space limitations. The arrangement shown where the throat washer follows closely the clip strap radius is a possible solution. A more robust two part propietary P clip is marketed which reduces the risk of damage to the clip during installation.

FIG.6 FAILURES AND REMEDIAL MEASURES ASSOCIATED WITH CLIPPING & CLAMPING DEVICES



Initial Damage Locations

See also figs 9 to 11 inclusive

Fig.8. View on Test Panel in Pressurised Fuselage Segment showing Damage Locations for Crack Propagation Studies

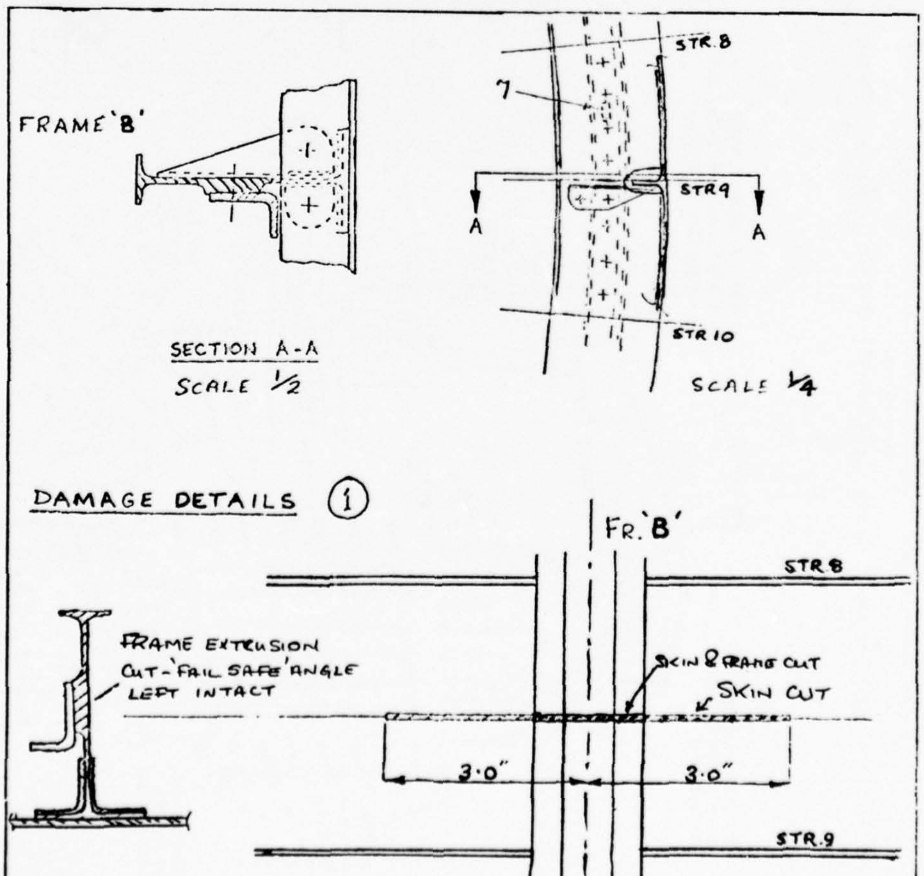
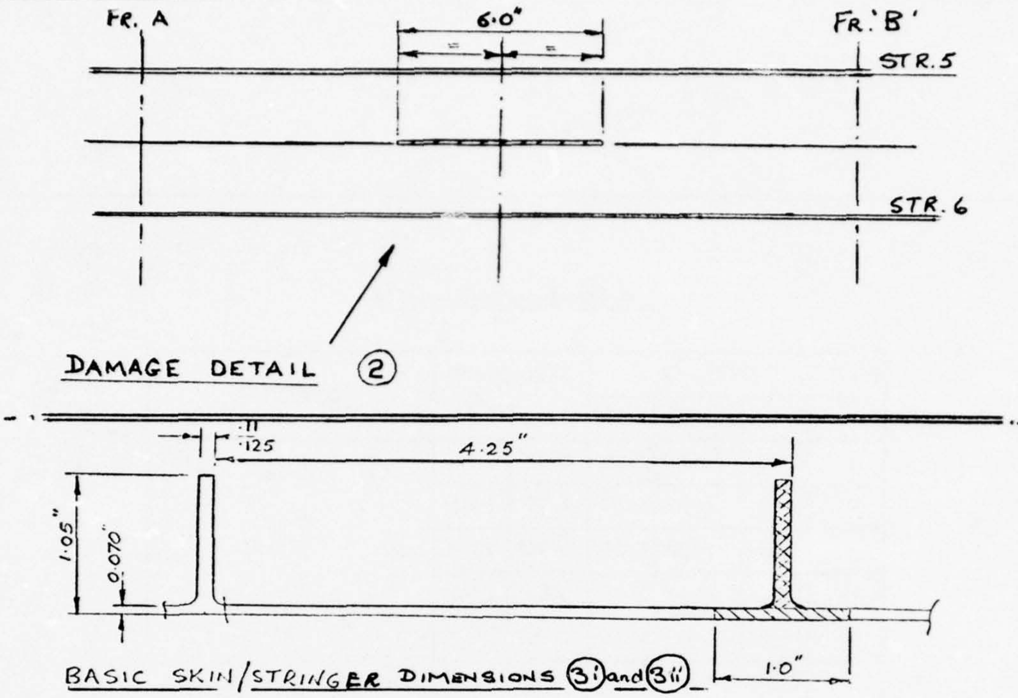


Fig.9 Pressurised Fuselage : Frame and Skin Cut : Damage Location (1)



Configuration (iii)

Damage detail location:

3 (i) Stringer location midway between frames B and C stringer 5 cut only (not skin)

3(ii) As 3(i) but between frame C and panel edge frame Str 5 cut and 1·0 ins of skin

Figure 10: Initial Damage at Configuration locations ii and iii (see also Fig.8)

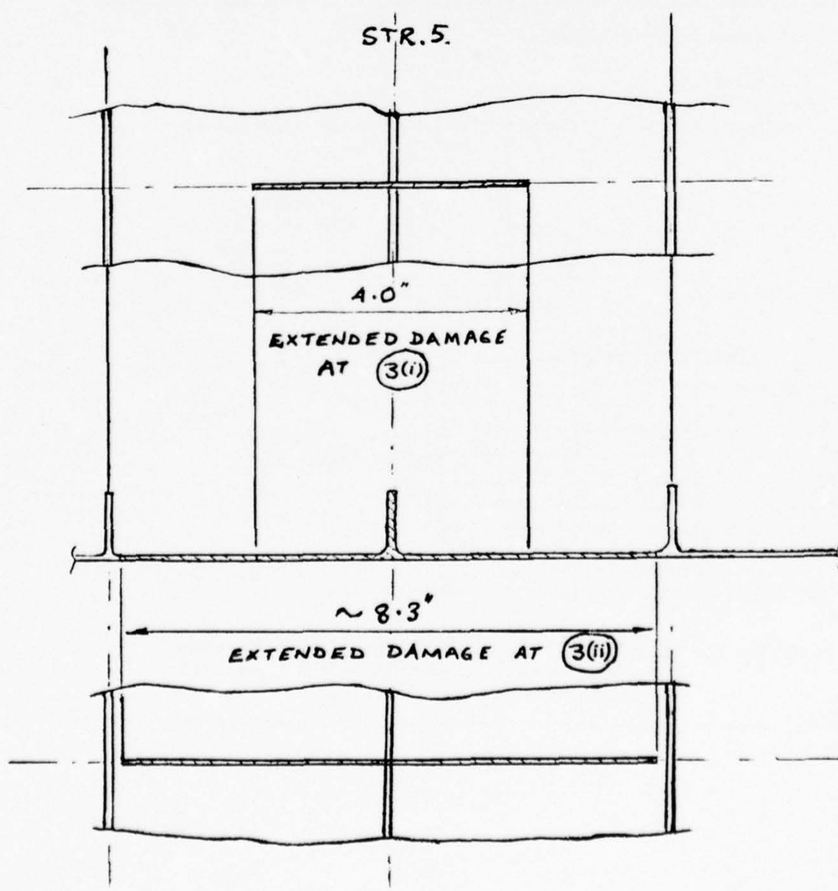


Figure 11. Extended configuration (iii) damage (see also fig.8)

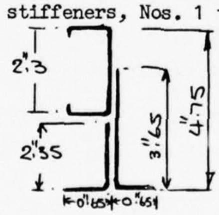
Test Panel Variant Details

PANEL No.	STIFFENER			SKIN t	FRAME PITCH	COMMENT
	t	HEIGHT	PITCH			
1	0·18	1·0	5·25	0·07	20·0	
2	0·18	0·705	5·25	0·07	20·0	
3	0·085	0·705	5·25	0·057	20·0	
4	0·085	0·705	4·0	0·057	20·0	
5	0·085	0·5	4·0	0·057	20·0	
6	0·085	0·5	4·0	0·057	10·0	Panel No.5 + 2 Frames (not tested)
7	0·079	0·7	5·25	0·055	20·0	Salvaged from Aircraft Panel, Radius=56·7ins (RR 58 material)
8	0·085	0·5	4·0	0·057	20·0	

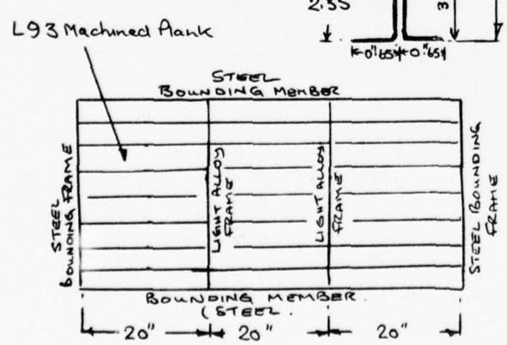
All dimensions in inches

t = thickness

All panels have 7 stiffeners, Nos. 1 to 6 are flat panels



Common Frame Confign. All Sections are 0·055" Thick



Typical Panel Layout

Figure 12: Details of Light Alloy Machined Plank Acoustic Fatigue Specimens as used in BAC/UK Government Research Contract.

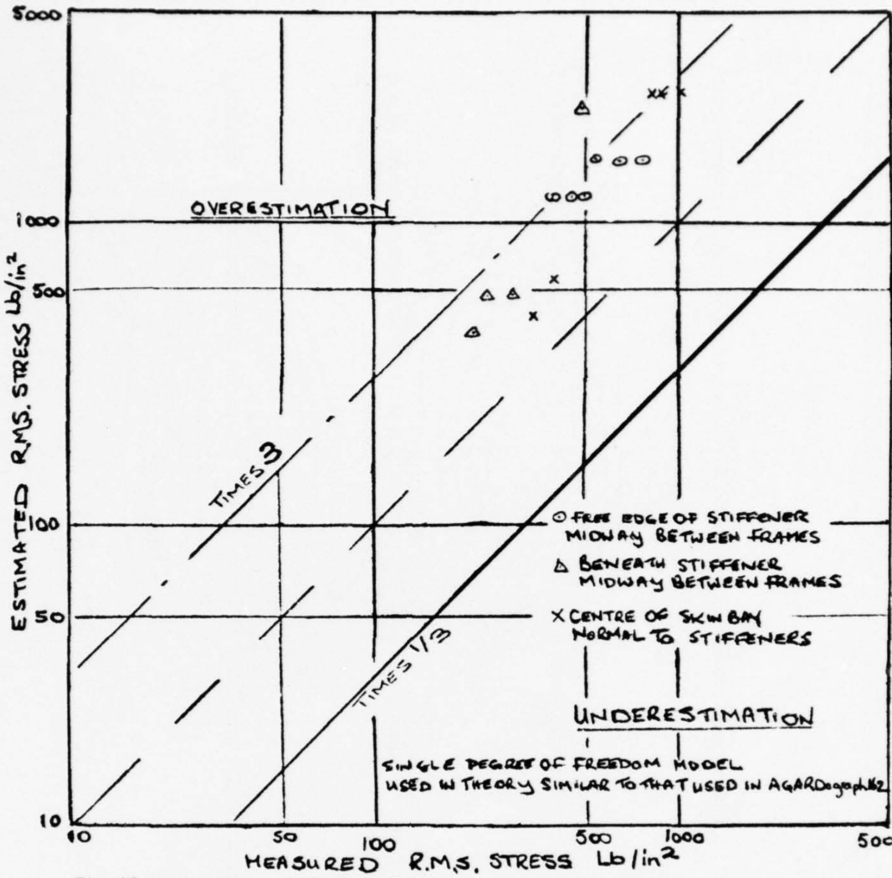


Fig 13 Comparison of Predicted Stresses using Single Mode Model with Measured Stresses due to Jet Noise : PANEL 3

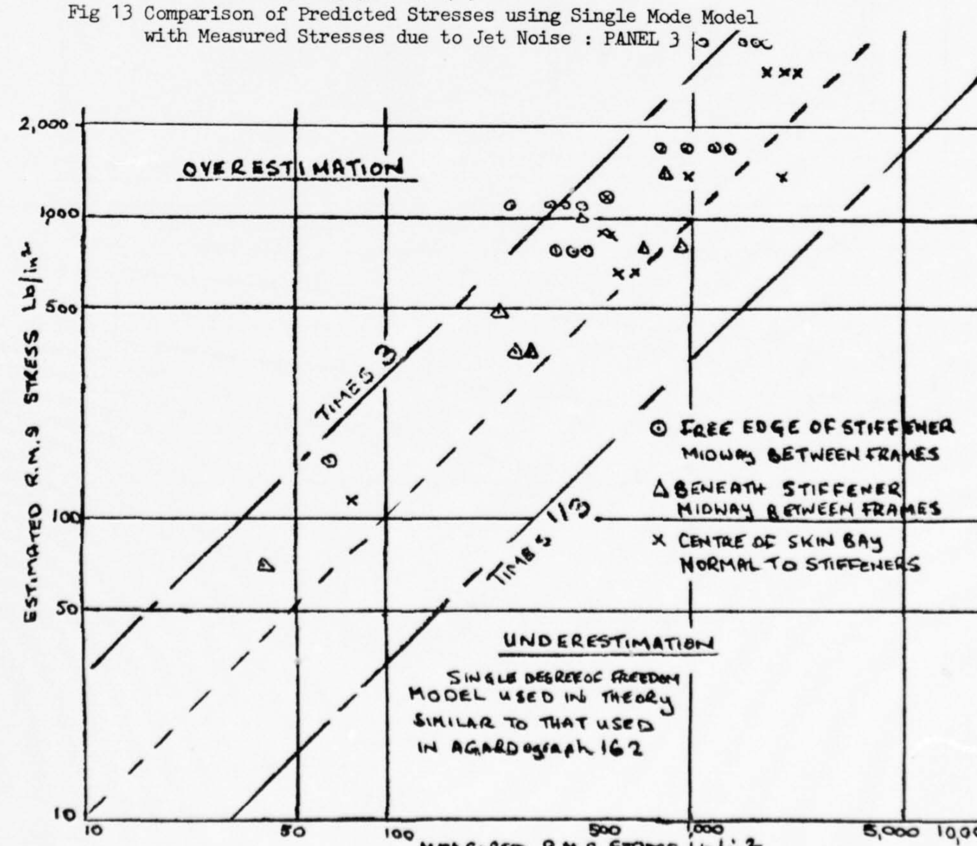


Fig 14 Comparison of Predicted Stresses using Single Mode Model with Measured Stresses due to Jet Noise : PANEL 7

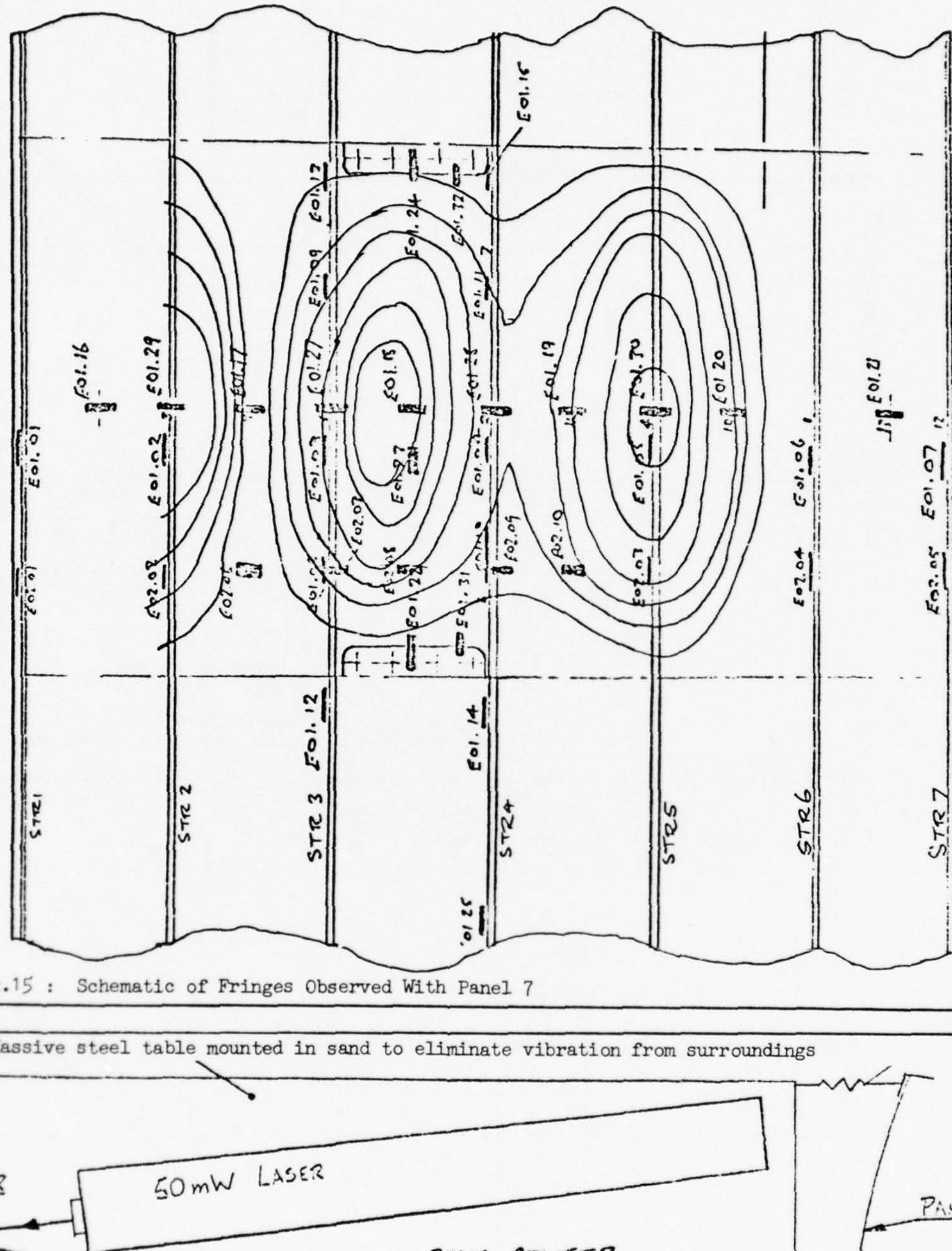


Fig.15 : Schematic of Fringes Observed With Panel 7

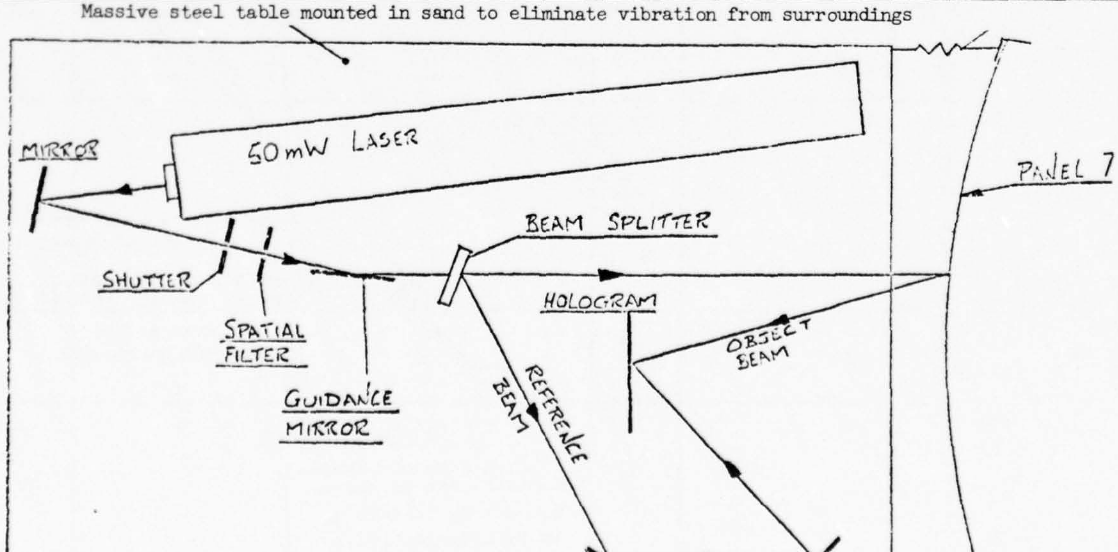
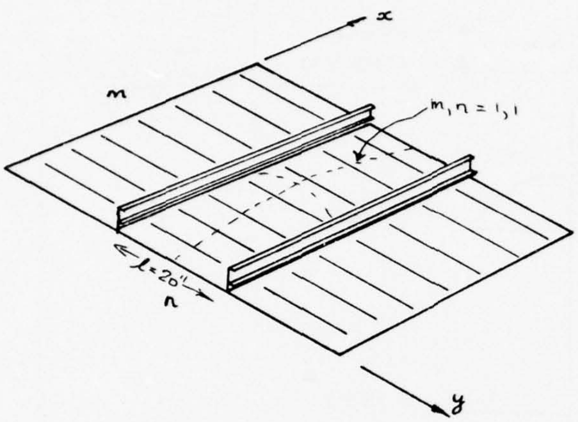
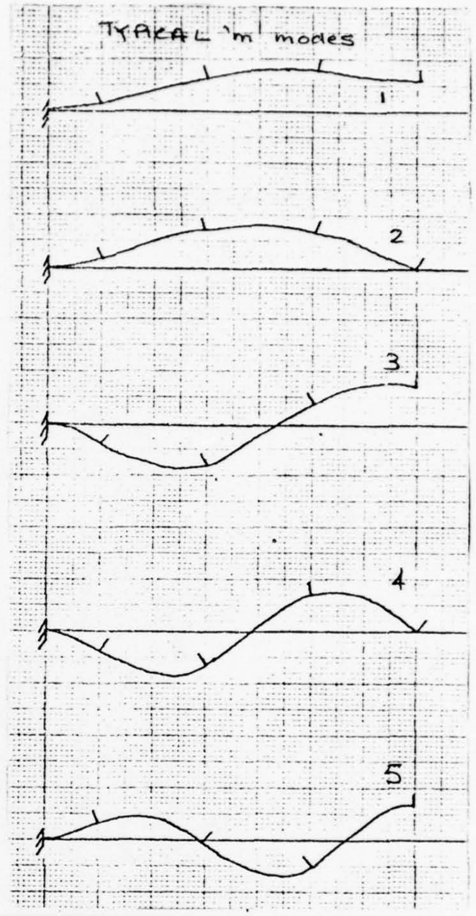


Figure 16 Schematic Diagram of Essential Features of Panel Holography Measurement





PANEL 1 CENTRE BAY VIBRATION ONLY				
m	VIPAL	ORTHOTROPIC PLATE	TRANSFER MATRIX	FINITE ELEMENT
1	208	215	119	146
2	210	218	123	147
3	219	221	131	166
4	231	227	144	168
5	248	240	166	185
6	272	261	192	186
7	312		222	238
8	332		306	481

(n = 1)

PANEL 1 NATURAL FREQUENCIES

(l = 20" ALL SIDES SIMPLY SUPPORTED)

Figure 17: BAC/Government Contract. Various Theoretical Assessments of Panel 1 Centre Bay Frequencies

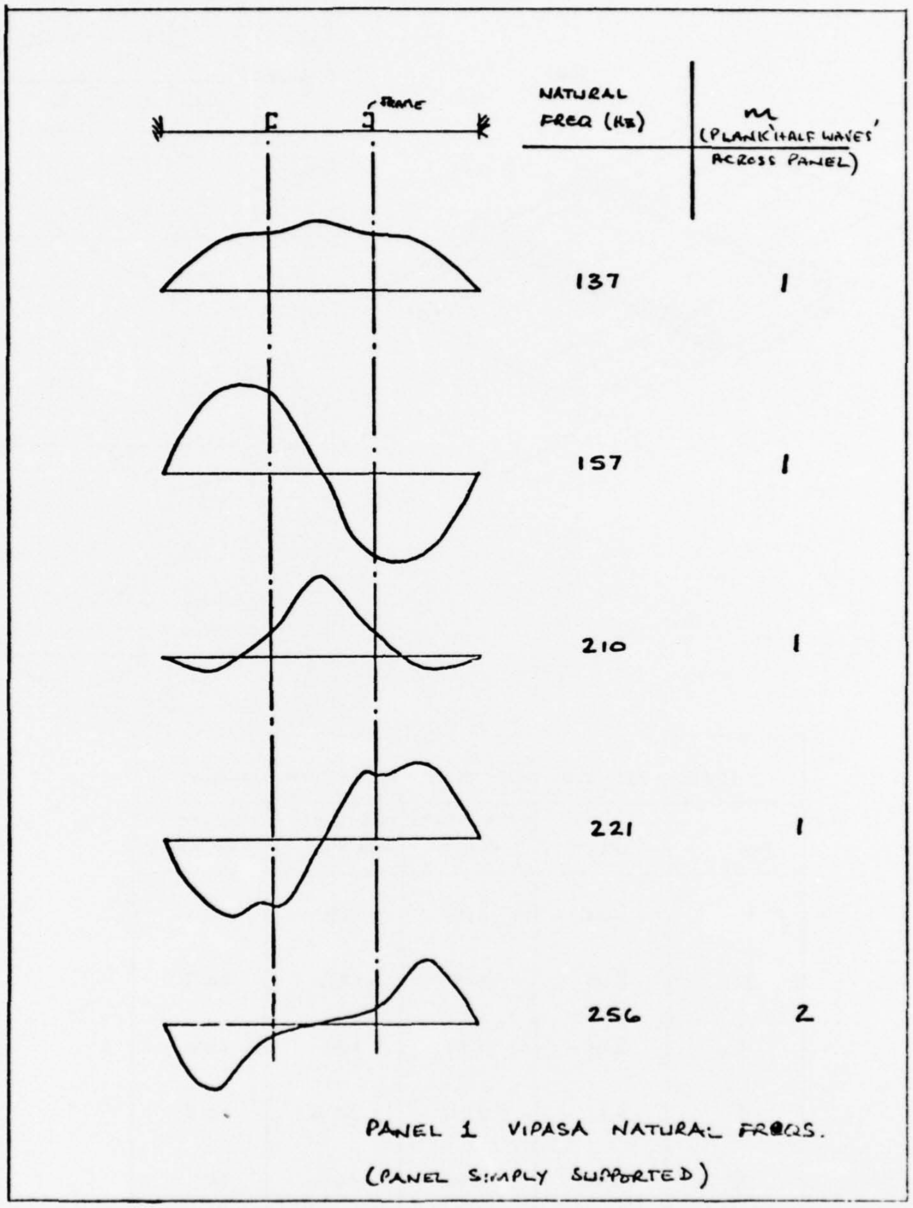


Figure 18: Theoretical Assessment of Multi Bay Panel Response Characteristics (see also Figs. 17 & 19)

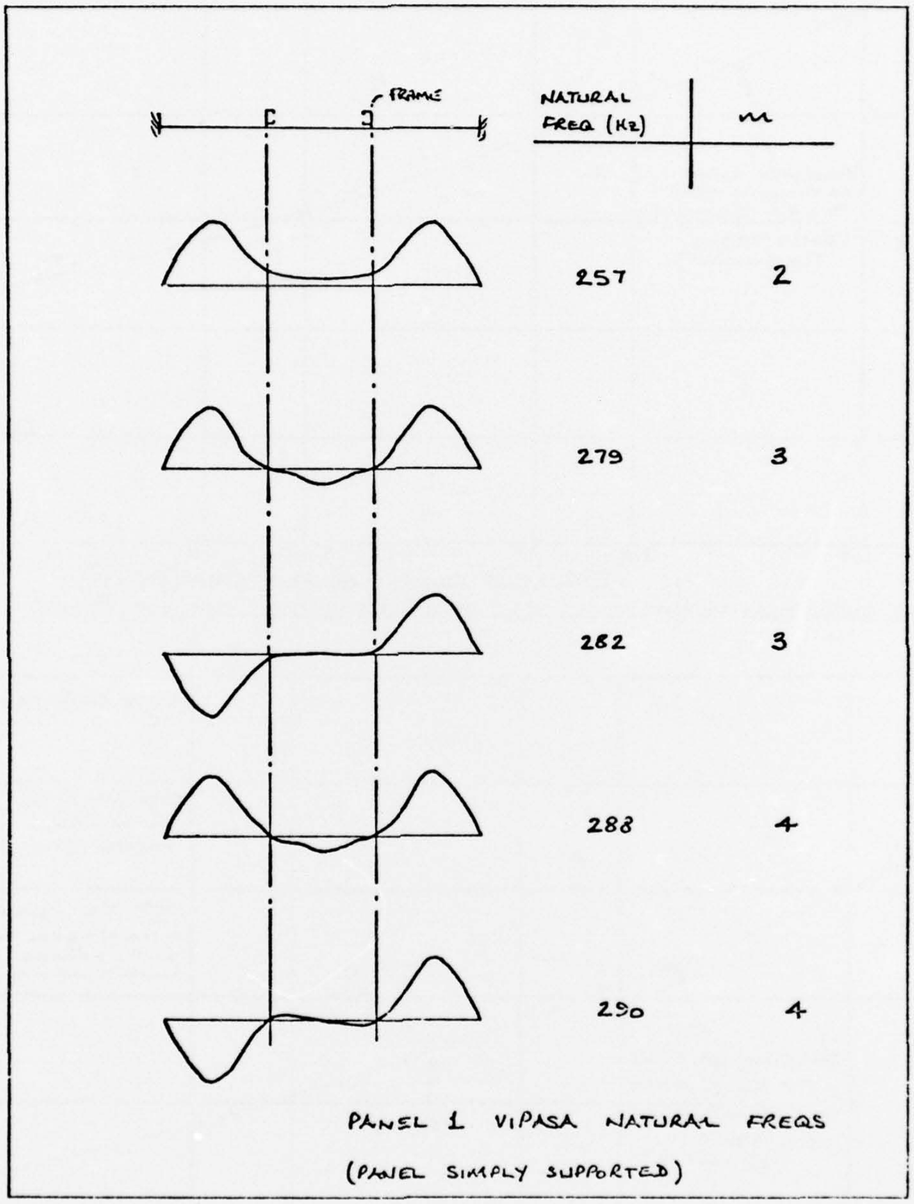


Figure 19: Theoretical Assessment of Multi Bay Panel Response Characteristics (see also Figs. 17 & 18)

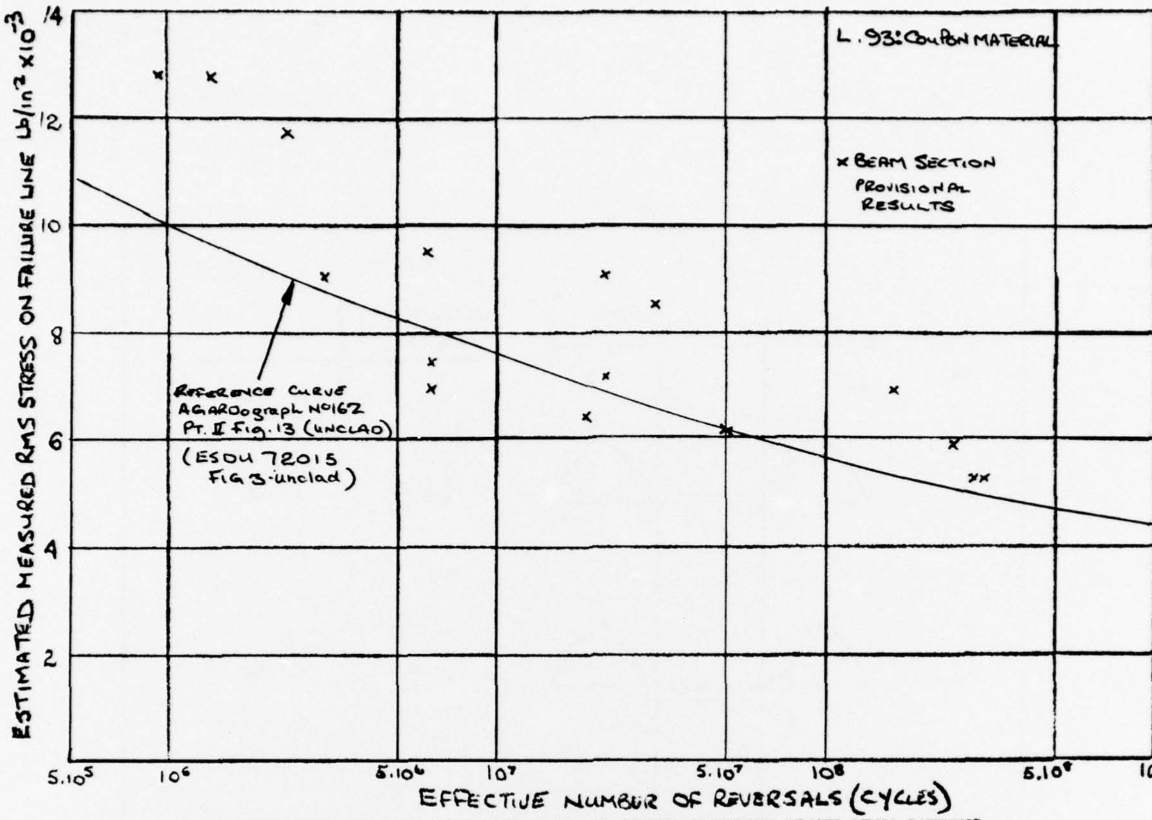


FIG.20 RANDOM VIBRATION FATIGUE DATA FOR L.93 AL.ALLOY MACHINED PLANK BEAM COUPONS.

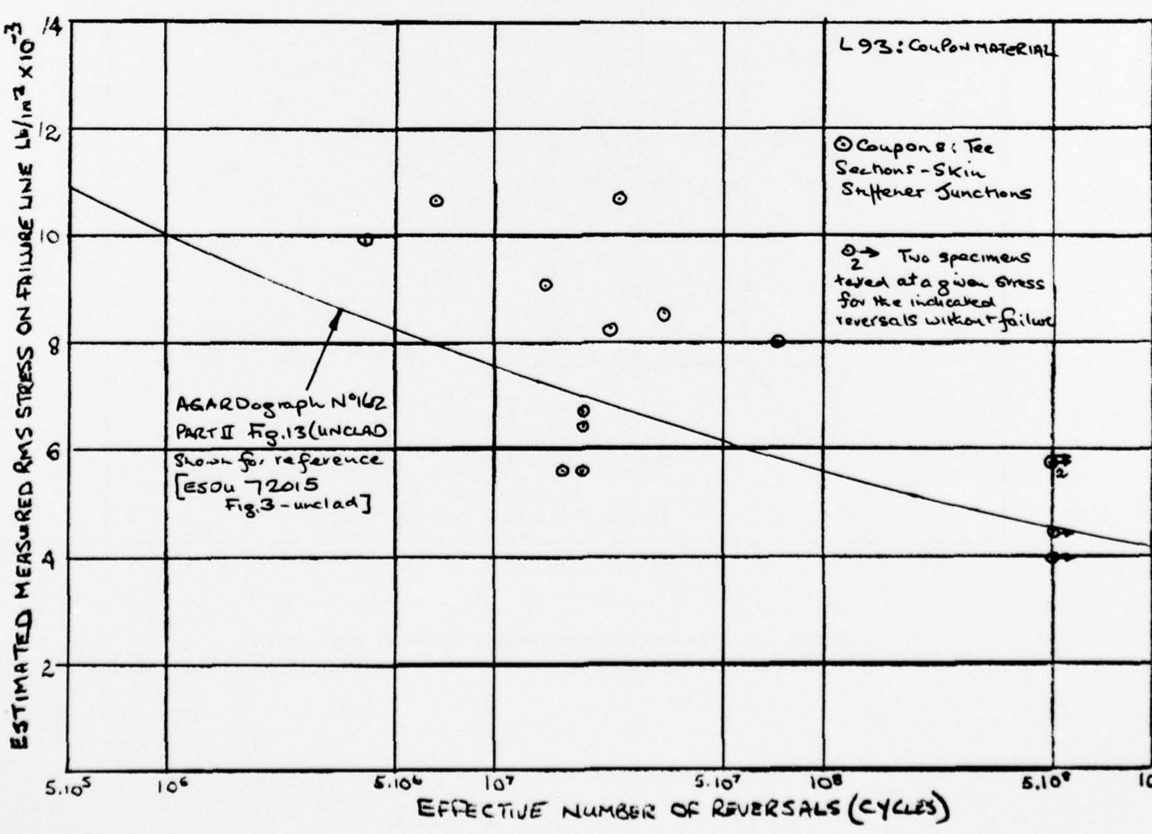


FIG.21 RANDOM VIBRATION FATIGUE DATA FOR L.93 AL.ALLOY MACHINED PLANK TEE COUPONS

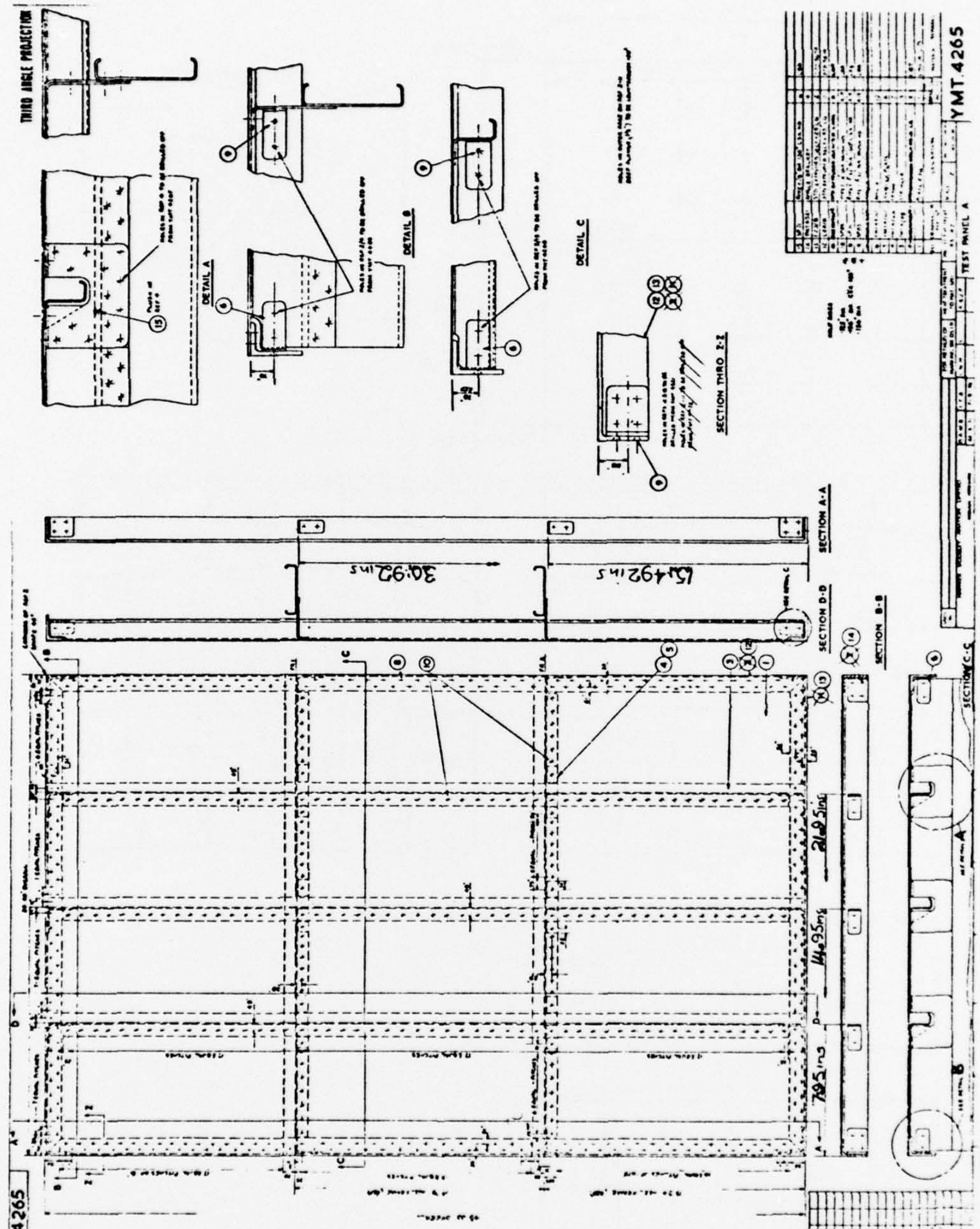


Figure 22: HSA/Government Contract. Details of Test Panel taken from Reference 14.

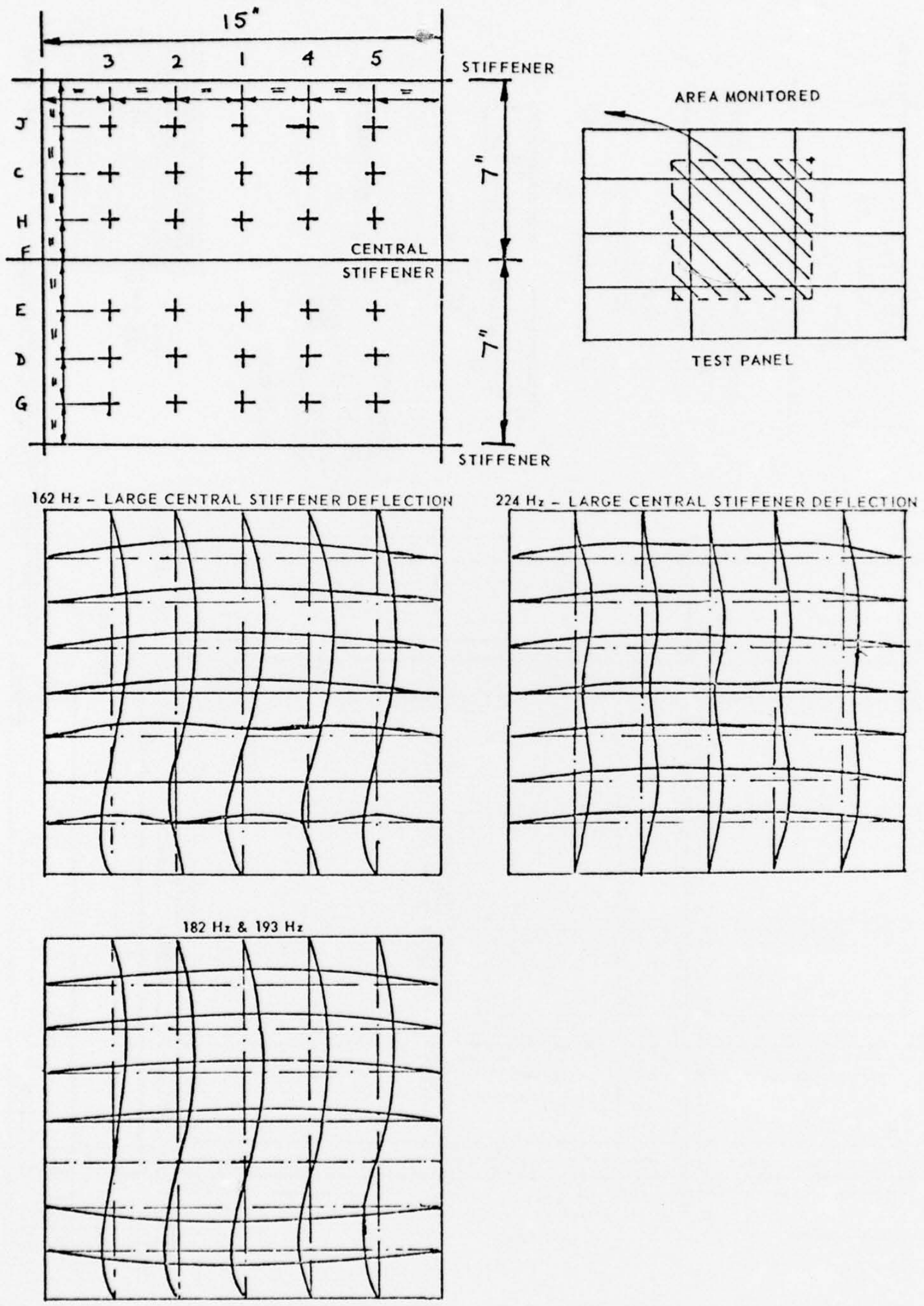


FIGURE 23. MEASURED MODE SHAPES USING DISCRETE MECHANICAL EXCITATION (taken from reference 14).
(CASE M3)

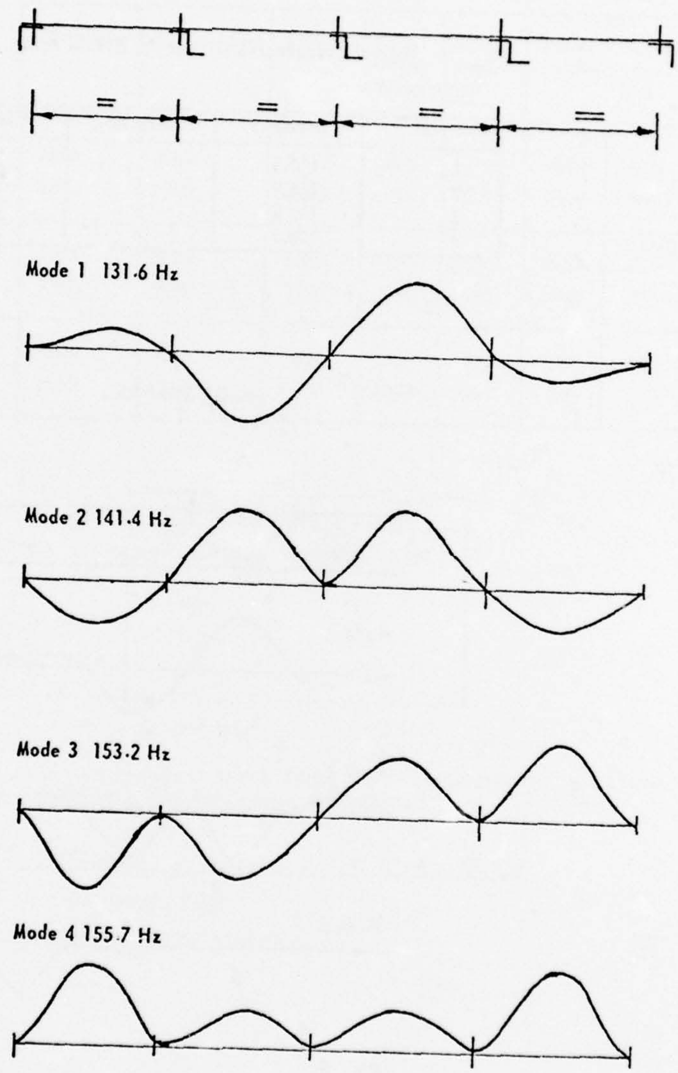


FIGURE 24 MODAL ANALYSIS-MODE SHAPES AND FREQUENCIES (taken from reference 14).

Natural Frequencies (Hz) of the Middle Array .

Mode No.	Frequency	Mode No.	Frequency
1	164.5	5	218.1
2	166.9	6	218.4
3	177.7	7	228.6
4	178.7	8	228.8

MODE SHAPES

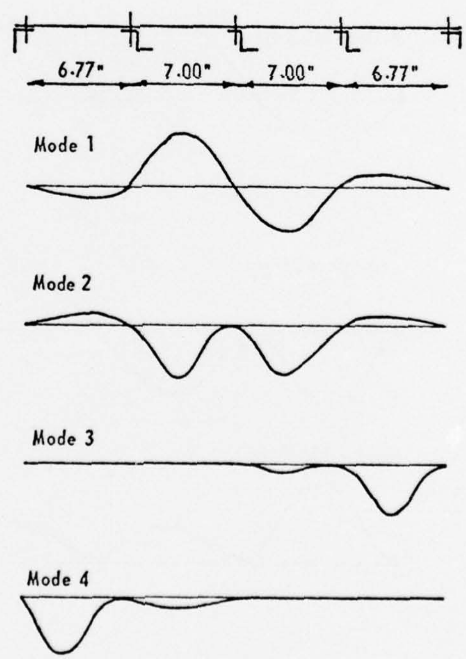


FIGURE 25 FINITE ELEMENT ANALYSIS OF THE MIDDLE ARRAY OF THE PANEL
(taken from reference 14.)

		Predicted Stress (p.s.i)					Measured Stress(psi)	
		Clarkson	Ballentine	Arcas	Wave Group Theory	Modal Analysis	Panel Alone	Panel in Box
Pos. 1	Bay Centre	2098	1048	2397	1900	1798	1018	560
	Bay Edge	4147	2100	4495	4092	2495	1549	899
Pos. 2	Bay Centre	3690	1846	3995	3492	3100	1557	848
	Bay Edge	7395	3693	7990	7294	4495	2049	1235
Pos. 3	Bay Centre	929	499	1050	858	799	280	238
	Bay Edge	1898	948	2098	1798	1099	329	239

	Measured S.P.L. *	
	O.A.S.P.L.	Spectrum Level
Pos. 1	148	119
Pos. 2	148	124
Pos. 3	139	112

* re 2.10^{-5} N/m^2

Predictions use spectrum level derived from measured third octave spectra (leading edge microphone).

FIGURE 26 PREDICTED AND MEASURED R.M.S. STRESS LEVELS

JET NOISE TEST

(taken from reference 14).

SUMMARISED DISCUSSIONS AND CONCLUSIONS

of the Review Meeting on

ACOUSTIC FATIGUE

Anthony J. Barrett
AGARD Structures and Materials Panel
Former Chairman

This summary is presented in two stages. Attention is first paid to the use made of the AGARD Structures and Materials Panel work in the field of acoustic fatigue and in particular of the data sheets published in AGARDograph 162, parts I to IV. Secondly there are gathered together the views expressed on the extent to which prevention or containment of acoustic fatigue still presents serious design problems and on variants of the phenomenon which are now being encountered.

The papers by Bayerdörfer, Incarbone and Eaton provided numerous examples of the application of the AGARDograph 162 data sheets to a range of military and civil aircraft designs. Generally the application of this work was reported to have had a successful outcome either in terms of the prediction of stress levels as later checked by test or in helping to reduce maintenance and retrofits to a tolerable level. The major criticism of the data sheets related to their scope and was coupled with a request for further information, in data sheet form, on a range of topics such as those specified by Eaton in the concluding remarks to his paper.

Two interesting by-products of the AGARD programme came to light during the review. Loubet recorded the usefulness of the data sheets as authoritative tools for the use of younger or less experienced engineers while Bayerdörfer reported the comment of the MBB Company on the value of the AGARD data sheets as a common basis for calculation when used in national and international co-operative aircraft design programmes. However, in respect both of the use of these data sheets by less experienced personnel and of their use by groups of personnel with differing technical backgrounds, Eaton's suggestion that the non-specialist requires additional information in the form of design instructions should not be overlooked.

In his opening remarks the Chairman of the Review Meeting, Professor B.L. Clarkson, had noted the progress which had been made since the Structures and Materials Panel first took an active interest in the subject of acoustic fatigue. The better understanding of the phenomena involved, the introduction of effective prediction and analytical methods and the advent of less noisy engines had done much to assist the designer in avoiding costly damage to structure and equipment resulting from acoustic excitation. In the same period, however, new aircraft configurations involving high lift devices such as blown flaps and attachment and impingement flows were introducing a further range of acoustic or 'pseudo-acoustic' loading problems. These cautionary observations by the Chairman were extended and amplified during the subsequent presentation of the papers and the discussion.

Kolb's observation that the utilisation of aircraft often far beyond their original design lives had caused re-occurrance of sonic fatigue failures was generally confirmed by other specialists throughout the discussion. There was also general support for the view that the development of high performance aircraft designed to extended lives, and most particularly STOL aircraft with large surfaces exposed to both noise and elevated temperature, could bring in its train a new range of critical safety problems.

Several speakers noted that the development and use of new materials and of new jointing techniques warranted a reappraisal of the current knowledge though some doubt was expressed on the extent to which a sufficient body of information existed particularly at high endurances and elevated temperatures. It might be some years before there was a sufficient knowledge on some of the newer materials from which could be distilled design information suitable for general application. In this connection the development of accelerated testing techniques and their establishment on a co-operative basis was recommended.

A lack of adequate loading data at the design stage, in regard to separated flows for example, was also noted. In order to overcome such a shortfall one speaker reported that he had used the AGARD data sheets to work backwards from a measured response in order to define a loading action albeit crudely. Such a procedure in conjunction with aerodynamic modelling might provide a helpful stopgap.

It is clear that the national reviews, and the discussions which followed, revealed a range of new problems of concern to those responsible for the structural integrity and damage tolerance of existing and future aerospace vehicles. The consensus view of the specialists who took part in the Review Meeting was that a revival of interest in this subject area by AGARD was timely. This view is justified in part in the detail of the individual papers presented and additionally by these general observations:-

1. Aircraft are now being utilised or configured for duties far beyond the design lives or missions which were common but a few years ago.

2. New problems are emerging in connection with STOL vehicles and related high lift devices.

In view of this revival of concern over acoustic fatigue type problems it is perhaps fortunate that the reviews presented at this meeting indicated the existence of at least some new raw data which might be amenable to refinement by co-operative effort. Example topics of this type include the effects of separated flow, impinging flow, buffet, armament launch bursts, flow over cavities (including control surface gaps) and dynamic response of structures that incorporate composites.

In contrast to the earlier interest in acoustic fatigue, which was often associated with effects existing only for relatively short parts of an aircraft mission, interest now centres particularly on effects which are in play over much longer time spans as a result, for example, of lifting surface blowing. For this reason the need to investigate the availability and quality of data relating to the performance of materials and structural components at high cycles, $> 10^8$, and at elevated temperature was identified. Beyond this, the possibility of developing reliable accelerated testing techniques requires further exploration.

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14. Abstract

In the late 1960's and early 1970's the Structures and Materials Panel of AGARD supported a programme of activities in the field of acoustic fatigue under the direction of a Working Group chaired by Mr A.H.Hall. A notable achievement of that programme included a survey undertaken by Professor B.L.Clarkson, the Panel's Co-ordinator on acoustic fatigue. This led to the preparation of an inventory of acoustic fatigue test facilities available within NATO, as at 1969, and a major symposium on acoustic fatigue held in September 1972. Finally, between 1970 and 1974, six of the NATO countries collaborated in the acquisition of design data and agreed on procedures for their analysis and interpretation by the Engineering Sciences Data Unit for the preparation of design data sheets. These data sheets were published by AGARD as the four parts of AGARDograph 162.

The Panel decided that, some two years after the data sheets had been introduced, a review should be made of acoustic fatigue activities in the NATO countries as a guide to the need for any additional action in this subject and also to assess the use which had been made of the data sheets which the Panel had published. This present publication includes the five national papers presented at the Review Meeting together with a summary of the discussions and conclusions reached.

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